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FORM PTO-1390 (REV 5-93) U S DEPARTMENT OF COMMERCE PATENT AND TRADEMARK OFFICE **TRANSMITTAL LETTER TO THE UNITED STATES DESIGNATED/ELECTED OFFICE (DO/EO/US) CONCERNING A FILING UNDER 35 U.S.C. 371**		ATTORNEY'S DOCKET NUMBER 225/50731 U S APPLICATION NO (if known, see 37 CFR 1.5) 10/009596
INTERNATIONAL APPLICATION NO. PCT/EP00/05337	INTERNATIONAL FILING DATE 9 June 2000	PRIORITY DATE CLAIMED 11 June 1999

TITLE OF INVENTION
METHOD OF DETECTING OBJECTS IN THE VICINITY OF A ROAD VEHICLE UP TO A CONSIDERABLE DISTANCE

APPLICANT(S) FOR DO/EO/US
Carsten KNOEPPEL and Uwe REGENSBURGER

Applicant herewith submits to the United States Designated/Elected Office (DO/EO/US) the following items and other information:

1.	X	This is a **FIRST** submission of items concerning a filing under 35 U.S.C. 371.		
2.		This is a **SECOND** or **SUBSEQUENT** submission of items concerning a filing under 35 U.S.C. 371		
3.	X	This express request to begin national examination procedures (35 U.S.C. 371(f) at any time rather than delay Examination until the expiration of the applicable time limit set in 35 U.S.C. 371(b) and PCT Articles 22 and 39(1).		
4.	X	A proper Demand for International Preliminary Examination was made by the 19th month from the earliest claimed priority date.		
5.	X	A copy of the International Application as filed (35 U.S.C. 371(c)(2)).		
		a.		is transmitted herewith (required only if not transmitted by the International Bureau).
		b.	X	has been transmitted by the International Bureau
		c.		is not required, as the application was filed in the United States Receiving Office (RO/US)
6.	X	A translation of the International Application into English (35 U.S.C. 371(c)(2)).		
7.	X	Amendments to the claims of the International Application under PCT Article 19 (35 U.S.C. 371(c)(3))		
		a.		are transmitted herewith (required only if not transmitted by the International Bureau).
		b.		have been transmitted by the International Bureau.
		c.		have not been made; however, the time limit for making such amendments has NOT expired.
		d.	X	have not been made and will not be made.
8.		A translation of the amendments to the claims under PCT Article 19 (35 U.S.C. 371(c)(3)).		
9.	X	An oath or declaration of the inventor(s) (35 U.S.C. 371(c)(4)) (unexecuted)		
10.	X	A translation of the annexes to the International Preliminary Examination Report under PCT Article 36 (35 U.S.C. 371(c)(5)).		

Item 11. to 16. below concern other document(s) or information included:

11.	X	An Information Disclosure Statement under 37 CFR 1.97 and 1.98.
12.		An assignment document for recording. A separate cover sheet in compliance with 37 CFR 3.28 and 3.31 is included.
13.	X	A FIRST preliminary amendment.
		A SECOND or SUBSEQUENT preliminary amendment.
14.	X	A substitute specification and marked-up copy thereof.
15.		A change of power of attorney and/or address letter.
16.	X	Other items or information:

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PATENT TRADEMARK OFFICE

a. Form PCT/IB/308;
b. 6 sheets of drawings showing Figs. 1-6;
c. International Preliminary Examination Report w/Annexes; and
d. International Search Report.

U.S. APPLICATION NO (if known, see 37 CFR 1 5	INTERNATIONAL APPLICATION NO	ATTORNEY'S DOCKET NUMBER
10/009596	PCT/EP00/05337	225/50731

17. [X] The following fees are submitted:				CALCULATIONS	PTO USE ONLY
Basic National Fee (37 CFR 1.492(a)(1)-(5)): Search Report has been prepared by the EPO or JPO $ 890.00					
International preliminary examination fee paid to USPTO (37 CFR 1.482) $ 710.00					
No international preliminary examination fee paid to USPTO (37 CFR 1.482) but international search fee paid to USPTO (37 CFR 1.445(a)(2) $ 740.00					
Neither international preliminary examination fee (37 CFR 1.482) nor International search fee (37CFR 1.445(a)(2) paid to USPTO $ 1040.00					
International preliminary examination fee paid to USPTO (37 CFR 1.482) and all claims satisfied provisions of PCT Article 33(2)-(4) $ 100.00					
ENTER APPROPRIATE BASIC FEE AMOUNT =				$ 890.00	
Surcharge of $130.00 for furnishing the oath or declaration later than [ ] 20 [X] 30 months from the earliest claimed priority date (37 CFR 1.492(e)).				$130.00	
Claims	Number Filed	Number Extra	Rate		
Total Claims	12 - 20 =	0	X $18.00	$	
Independent Claims	2 - 3 =	0	X $84.00	$	
Multiple dependent claims(s) (if applicable)			+ $280.00	$	
TOTAL OF ABOVE CALCULATIONS=				$1020.00	
Applicant claims Small Entity Status (See 37 CFR §1.27) [ ] yes [ ] no. Reduction by 1/2 for filing by small entity, if applicable.				$	
SUBTOTAL =				$1020.00	
Processing fee of $130.00 for furnishing the English translation later than [ ] 20 [ ] 30 months from the earliest claimed priority date (37 CFR 1.492(f)).				$	
TOTAL NATIONAL FEE =				$1020.00	
Fee for recording the enclosed assignment (37 CFR 1.21(h)). The assignment must be accompanied by an appropriate cover sheet (37 CFR 3.28,3.31). $40.00 per property +				$	
TOTAL FEE ENCLOSED =				$1020.00	
				Amount to be: refunded	$
				Charged	$

a. [X] A check in the amount of $1020.00 for the filing fee is enclosed

b. [ ] Please charge my Deposit Account No. ______ in the amount of $______ to cover the above fees. A duplicate copy of this sheet is enclosed.

c. [X] The Commissioner is hereby authorized to charge any additional fees, which may be required, or credit any overpayment to Deposit Account No. 05-1323 . A duplicate copy of this sheet is enclosed.

NOTE: Where an appropriate time limit under 37 CFR 1.494 or 1.495 has not been met, a petition to revive (37 CFR 1.137(a) or (b)) must be filed and granted to restore the application to pending status.

SEND ALL CORRESPONDENCE TO:	
Crowell & Moring, L.L.P.	SIGNATURE
P.O. Box 14300	Jeffrey D. Sanok
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	December 11, 2001
	DATE

JDS:pct

Attorney Docket: 225/50731
PATENT

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Applicant: CARSTEN KNOEPPEL ET AL

Serial No.: NOT YET ASSIGNED PCT NO.: PCT/EP00/05337

Filed: DECEMBER 11, 2001

Title: METHOD OF DETECTING OBJECTS WITHIN A WIDE RANGE OF A ROAD VEHICLE

PRELIMINARY AMENDMENT

Box PCT
Commissioner for Patents
Washington, D.C. 20231

Sir:

Please enter the following amendments to the specification and claims, as amended by way of Annexes to the International Preliminary Examination Report for PCT/EP00/05337, prior to the examination of the application during the U.S. National Phase.

IN THE SPECIFICATION:

Submitted herewith is a substitute specification and marked-up copy thereof which includes the changes made by way of the Annexes to the International Preliminary Examination Report.

IN THE CLAIMS:

Please cancel claims 1-9 presently in the application and substitute new claims 10 - 21 as follows:

--10. (new) A method of detecting objects in a vicinity of a road vehicle up to a considerable distance, in which a distance from a moving or stationary vehicle to one or more objects is calculated by distance-based image segmentation using stereo image processing, and characteristics of the detected objects are determined by object recognition in the segmented image regions, the method comprising the acts of:

determining image regions of elevated objects and/or flat objects;

detecting elevated objects and/or flat objects by combining 3D points in accordance with predetermined criteria, the elevated objects being determined through features with similar distance values and the flat objects being determined through features with similar height values;

tracking over time relevant detected objects and determining the distance and lateral position of the relevant detected objects relative to the road vehicle in order to assess dynamic behavior of the relevant detected objects;

determining object hypothesis for performing object recognition, said object hypothesis being verified by comparison with object models;

scanning segmented image regions in accordance with predetermined, statistically verified 2D features of particular relevant detected objects to be recognized; and

comparing the particular relevant detected objects using a neural network for classifying a specific object type.

8 ~~11~~. (new) The method according to claim 10, wherein elevated relevant detected objects are road vehicles and flat relevant detected objects are road markings and boundaries.

9 ~~12~~. (new) The method according to claim 10, further comprising the act of determining a relative position and a relative speed of the relevant detected objects relative to one another and to the road vehicle by evaluating a distance measurement, in order to determine an accurate road-lane object association.

10 ~~13~~. (new) The method according to claim 12, wherein the relative position and the relative speed of the relevant detected objects are determined in order to assess a relevance of the detected objects to a particular situation.

11 ~~14~~. (new) The method according to claim 11, further comprising the act of determining a relative position and a relative speed of the relevant detected objects relative to one another and to the road vehicle by evaluating a distance measurement, in order to determine an accurate road-lane object association.

12
~~15~~. (new) The method according to claim 14, wherein the relative position and the relative speed of the relevant detected objects are determined in order to assess a relevance of the detected objects to a particular situation.

13
~~16~~. (new) The method according to claim 10, further comprising the acts of:

scanning one of recorded pairs of stereo images for significant features of objects to be registered;

determining a spacing of the significant features by comparing respective features in a stereo image from a pair of stereo images with the same, corresponding features, in the other stereo image from the pair of stereo images recorded at the same time; and

wherein disparities that occur are evaluated via cross correlation techniques.

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~~17~~. (new) The method according to claim 11, further comprising the acts of:

scanning one of recorded pairs of stereo images for significant features of objects to be registered;

determining a spacing of the significant features by comparing respective features in a stereo image from a pair of stereo images with the same,

corresponding features, in the other stereo image from the pair of stereo images recorded at the same time; and

wherein disparities that occur are evaluated via cross correlation techniques.

15 ~~18~~. (new) The method according to claim 12, further comprising the acts of:

scanning one of recorded pairs of stereo images for significant features of objects to be registered;

determining a spacing of the significant features by comparing respective features in a stereo image from a pair of stereo images with the same, corresponding features, in the other stereo image from the pair of stereo images recorded at the same time; and

wherein disparities that occur are evaluated via cross correlation techniques.

16 ~~19~~. (new) The method according to claim 16, wherein by determining the spacing of the significant features in a pixel range, 3D points in the road vehicle environment are determined relative to a coordinate system of a measuring device performing the detecting method.

17 ~~20~~. (new) The method according to claim 10, wherein said objects are detected by at least one of radar, infrared sensing, and stereoscopic or mono sensing.

18 ~~21~~. (new) A method of detecting and recognizing an object in a vicinity of a road vehicle, the method comprising the acts of:

performing distance-based image segmentation to calculate a distance from the road vehicle to an object to be detected;

scanning the segmented image regions in accordance with predetermined, statistically verified 2D features of the object to be detected; and

comparing the detected object using a neural network for classifying it as a specific object type.--

<u>IN THE ABSTRACT</u>:

Please add an Abstract of the Disclosure submitted herewith on a separate page.

(Applicants' remarks are set forth herein below starting on the following page).

REMARKS

Entry of the amendments to the specification and claims, as amended by way of Annexes to the International Preliminary Examination Report for PCT/EP0005337, before examination of the application in the U.S. National Phase is respectfully requested.

If there are any questions regarding this Preliminary Amendment or this application in general, a telephone call to the undersigned would be appreciated since this should expedite the prosecution of the application for all concerned.

If necessary to effect a timely response, this paper should be considered as a petition for an Extension of Time sufficient to effect a timely response, and please charge any deficiency in fees or credit any overpayments to Deposit Account No. 05-1323 (Docket #225/50731).

Respectfully submitted,

December 11, 2001

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--ABSTRACT OF THE DISCLOSURE

The invention relates to a method of detecting objects within a wide range of a road vehicle. According to said method, the distance between a moving or stationary vehicle and one or more objects is calculated by distance-based image segmentation using stereoscopic image processing techniques and the properties of the detected objects are determined by object recognition in the segmented image areas. Image areas of three-dimensional and/or flat objects are detected and said three-dimensional and/or flat objects are detected by clustering 3D pixels according to defined criteria. Three-dimensional objects are determined by features with similar distance values and flat objects by features with similar height values.--

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Attorney Docket: 225/50731
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IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Applicant: CARSTEN KNOEPPEL ET AL

Serial No.: NOT YET ASSIGNED PCT NO.: PCT/EP00/05337

Filed: DECEMBER 11, 2001

Title: METHOD OF DETECTING OBJECTS WITHIN A WIDE RANGE OF A ROAD VEHICLE

SUBMISSION OF SUBSTITUTE SPECIFICATION

Box PCT
Commissioner for Patents
Washington, D.C. 20231

Sir:

Attached is a Substitute Specification and a marked-up copy of the original specification. I certify that said substitute specification contains no new matter and includes the changes indicated in the marked-up copy of the original specification.

Respectfully submitted,

December 11, 2001

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6/PRTS

Method of detecting objects in the vicinity of a road vehicle up to a considerable distance

BACKGROUND AND SUMMARY OF THE INVENTION

[0001] The invention relates to a method of detecting objects in the vicinity of a road vehicle up to a considerable distance, in which the distance from a moving or stationary vehicle to one or more objects is calculated by distance-based image segmentation using stereo image processing, and characteristics of the detected objects are determined by object recognition in the segmented image regions. Image regions of elevated objects and/or flat objects are determined and the elevated objects and/or flat objects are detected by combining (clustering) 3D points in accordance with predetermined criteria. The elevated objects are determined through features with similar distance values and the flat objects are determined through features with similar height values. The relevant objects are followed over time (tracking) and their distance and lateral position relative to the particular vehicle is determined in order to assess the dynamic behavior of the relevant objects.

[0002] In order to assist the driver of a motor vehicle in road traffic, driver assistance systems have been developed, which are suitable for detecting situations in the road traffic which are anticipated to be hazardous. Such driver assistance systems can either warn the driver, on the basis of his behavior, or intervene in the management of the vehicle. The intention here is to increase driving safety, to relieve the driver of monotonous driving tasks and, therefore, for driving to become more convenient.

[0003] On account of the high requirements on the

reliability of systems which increase safety, at the current time, it is predominantly convenience systems which are available on the market. Examples of this are parking aids and intelligent cruise control systems. Driver assistance systems which increase safety are intended to register the surrounding traffic situation to an ever increasing extent and to take it into account.

[0004] EP 0 558 027 B1 discloses a device for registering the distance between vehicles. In the case of this device, a pair of image sensors generates an image of an object, which is displayed to the driver. One region of this image is subdivided into windows. The distances from the driving vehicle to the object, which is located in the respective window, are registered. In this case, the distances are calculated by comparing two items of image information recorded by different image sensors in different windows. On the basis of the determined distance information, the respective object is determined. A grid which divides the relevant image region is used. The grid surrounds the object to be registered and supplies further image information. The symmetry of this image information is determined, and the existence of a vehicle travelling in front is predicted by determining a level of stability of a horizontal movement of a line of symmetry and a second level of stability of the distances over time.

[0005] This known registration device is used for the purpose of registering and recognizing vehicles located in front of the moving vehicle. The reliable recognition of objects is achieved only in the near region, however, since there the simple registration of lines of symmetry can be carried out with sufficient stability. In the remote region,

this simple registration of symmetry is no longer adequate on its own because of the low resolution in the image and the resulting inaccuracy in the determination of the object.

[0006] However, high requirements have to be placed on reliable object recognition in particular, in order that the driver is not given any erroneous information, which can lead to erroneous and hazardous reactions. In the case of intelligent systems, the vehicle itself could react in a manner presenting a traffic hazard, on the basis of the erroneous information. Reliable information is imperative, for example in accurate-lane recognition of vehicles at a considerable distance, both in and counter to the actual direction of travel.

[0007] For the recognition of interesting patterns, DE 42 11 171 A1 proposes a method which applies the cross relation of small singular extracts from the entire pattern of interest by means of block-by-block progressive image recognition via a trained classification network.

[0008] DE 43 08 776 C2 discloses a device for monitoring the outer space around a vehicle, which is travelling over one lane on a road. The lane is defined by extended white lines. By means of image processing, the course of the road is determined by using three-dimensional position information from sections of the white lines. By utilizing the three-dimensional position information from the white lines, the white lines are separated from three-dimensional objects. For each section, the vertical extent of possible objects is determined. As a result, the coordinates for three-dimensional objects of interest, such as motor vehicles, motor cycles or pedestrians, can be defined in the coordinate system of the

vehicle. In addition, it is possible to determine which object is concerned.

[0009] The procedure described in DE 43 08 776 C2 for monitoring the outer space around a vehicle requires a great deal of computation. It is always necessary to determine the course of the registered region of the road, in order to be able to determine the position of objects in this road course. Since only a limited amount of computing power is available in a motor vehicle, such a monitoring device is ill-suited to practical use. In addition, the known monitoring device is always referred to the presence of white boundary lines, which may not be found on the course of all roads.

[0010] EP-A-0 874 331 discloses the practice of dividing up a distance image into regions in the lateral direction away from the vehicle. In this case, a histogram relating to the distance values in the individual regions is drawn up, in order to determine the distances of individual objects from these histograms. The possibility of a collision or contact with objects or other vehicles on the roadway is determined from the position and size of the objects or vehicles. The relative speed of the objects in relation to the particular vehicle is determined by tracking the objects. A reliable statement relating to the relevance of the objects to the situation is possible only after a very computationally intensive procedure, which calls a practical application in road vehicles into question.

[0011] The object of the invention is to specify a method of detecting objects in the vicinity of a road vehicle up to a considerable distance which permits the reliable registration of objects, in particular of vehicles in front of and/or

behind the road vehicle and their relevance to the situation on the basis of its position relative to the road vehicle.

[0012] According to the invention, this object is achieved by determining for the purpose of object recognition, object hypotheses, which are verified by comparison with object models. Segmented image regions are scanned in accordance with predetermined, statistically verified 2D features of the objects to be recognized. The detected objects are compared by using a neural network for the classification of a specific object type. The subclaims relate to advantageous developments of the subject of the invention.

[0013] Accordingly, a method of detecting objects in the vicinity of a road vehicle up to a considerable distance is provided, in which the distance from a moving or stationary vehicle to one or more objects is calculated by distance-based image segmentation by means of stereo image processing, and characteristics of the detected objects are determined by object recognition in the segmented image regions.

[0014] Determining the characteristics of the detected objects is intended to serve to clarify their relevance to the particular vehicle and therefore contribute to the understanding of the situation.

[0015] The detection can preferably be carried out to the front or to the rear and employed, for example, to warn of traffic jams, for distance control from the vehicle in front or for monitoring the rear space. In this case, an important point of view is that the relevance to the situation or the potential hazard of the detected objects is determined from their distance to the particular vehicle and the determined

relative speed.

[0016] Instead of evaluating pairs of stereo images, which are recorded by a stereo arrangement comprising optical sensors or cameras, in principle, even individually recorded images of different origin can be evaluated in order to determine the distance.

[0017] Image regions of elevated objects and/or flat objects are determined. Elevated objects and/or flat objects are detected by combining 3D points in accordance with predetermined criteria. Combining is also designated clustering. In this case, the elevated objects are determined through features with similar distance values and flat objects are determined through features with similar height values. By means of this procedure, objects can be recognized and assessed not only reliably with regard to their distance but also with regard to specific features. Distinguishing between elevated and flat objects is therefore easily possible.

[0018] Features of similar distance values and/or similar height are combined in order to form clusters. This distinction between elevated and flat objects is very important for reliable object recognition, for example the recognition of other motor vehicles, and the distinction from road markings. Since appropriately high computing powers can be implemented nowadays in modern motor vehicles, image segmentation of this type by means of distance determination and clustering can be carried out reliably and quickly.

[0019] The relevant objects are followed over time and their distance and lateral position relative to the particular vehicle are determined, in order to assess the dynamic

behavior of the relevant objects. Only with knowledge of the dynamic behavior of the determined objects are practical reactions of the driver or of the vehicle possible. An "anticipatory" mode of driving is therefore promoted.

[0020] Furthermore, by means of this tracking, as it is known, phantom objects which occur sporadically can be suppressed, and the entire recognition performance can be increased. In this way, the number of extracted image regions to be classified in the image can be reduced, if these are checked for their local consistency by means of simple time tracking. By means of tracking the detected objects over time, the object characteristics, such as the distance, relative speed and relative acceleration, can be freed of measurement noise, for example by using a Kalman filter.

[0021] For the purpose of object recognition, object hypotheses are determined, which are verified by comparison with object models.

[0022] In this way, for the purpose of object recognition, the segmented image regions may be scanned in accordance with predetermined, statistically verified 2D features of the objects to be recognized, and the detected objects may be compared by using a neural network for the classification of a specific object type. In this way, reliable object recognition is carried out.

[0023] The detected elevated objects may be, in particular, road vehicles, signposts, bridge columns, lamp posts and so on, whereas the detected flat objects may be, in particular, road markings and boundaries such as curb stones, crash barriers and so on. In this way, for example, the position of

a road vehicle on a specific road lane can be determined in a simple way.

[0024] In addition, it is advantageous to know the relative position and the relative speed of the detected objects relative to one another and to the moving vehicle, in order to determine the relevance of the detected objects to the situation. To this end, the distance measurement is evaluated, and an accurate road-lane object association is determined.

[0025] During the image segmentation, one of the recorded pairs of stereo images can be scanned for significant features of objects to be registered. The spacing of the significant features may then be determined by means of cross-relation by comparing the respective features in a stereo image from the pair of stereo images with the same, corresponding features in the other stereo image from the pair of stereo images, recorded at the same time. The disparities which occur are evaluated.

[0026] By determining the spacing of significant features in the pixel range, 3D points in the real world are determined relative to the coordinate system of the measuring device. The information obtained in this way from 3D points is therefore determined from different objects, such as vehicles, road markings, crash barriers, and so on.

[0027] In addition to the above-described stereo-based approach, in principle object registration methods based on radar and/or infrared signals in the remote range are also possible.

BRIEF DESCRIPTION OF THE DRAWINGS

[0028] Further advantages, features and details of the invention become clearer by using the following description in conjunction with the appended drawings, in which:

[0029] Fig. 1 shows a schematic representation of the method steps according to the invention;

[0030] Fig. 2 shows a schematic representation to clarify the principle of the distance determination in the case of cameras with the same focal length arranged in parallel;

[0031] Fig. 3 shows a schematic representation to clarify the principle of the correspondence search by means of cross correlation;

[0032] Fig. 4 shows a schematic representation to clarify the principle of the 2D feature extraction in the case of evaluation by a neural network according to the invention;

[0033] Fig. 5 shows a schematic representation to clarify the principle of coordinate normalization; and

[0034] Fig. 6 shows a representation of a distance profile of an approaching vehicle.

DETAILED DESCRIPTION OF THE DRAWINGS

[0035] In the following text, the image segmentation 1 by means of stereo image processing is described, during which elevated objects 2 are detected. This is carried out through clustering 3 individual features with similar distances. Then, a vehicle recognition method 5, 6 will be presented, with which road vehicles in the segmented image regions are

recognized. For this purpose, features typical of vehicles are extracted 6 and then compared with the internal vehicle model depiction 5 from a neural network 8. The basic procedure is shown schematically in Figure 1.

[0036] Mono image processing is in principle also possible, given the use of similar means and a similar procedure.

[0037] The characteristic that road vehicles are elevated by comparison with the road is used for the method of image segmentation presented here. To this end, use is made of a stereo camera system, with which it is possible to determine the distances of significant features which occur in the camera image on road vehicles. By means of this information, a statement about elevated objects 4 is possible. The continually increasing computing power, which is available in the vehicle nowadays, permits real-time analysis of pairs of stereo images.

[0038] It is also possible to determine reliably on which lane a registered road vehicle is located. It is then possible to make a statement about the relevance of this registered road vehicle to the situation, on the basis of its position relative to the particular vehicle. The driver and/or the particular vehicle can then react accordingly.

[0039] Although radar systems suitable for vehicles do not offer adequate lateral resolution for lane association, infrared systems have resolution and range problems and ultrasound can generally be used for the near range, it is in principle conceivable to employ these systems instead of or in combination with stereo camera systems.

[0040] The principle of distance determination in the case of the parallel camera arrangement used is represented in Figure 2 on the basis of the pinhole camera model. The point P in the world (camera's field of view) is projected onto the sensor surfaces of each camera via the projection centers. u_0 and u_1 represent the deviation from the projection center. Their difference

$$\Delta u = u_0 - u_1$$

is designated the disparity Δu. By means of trigonometry and the sizes of the camera arrangement (focal length f and base width b), the distance d can be calculated.

$$d = \frac{f \cdot b}{\Delta u}$$

Here, b represents the base width, f the focal length and d the distance to the point P. u_0 and u_1 are the distances of the projections of the point P onto the sensor surface.

[0041] In the first processing step in the image segmentation, a search for significant features is carried out in one of the pairs of stereo images. A corresponding display (not shown) on a monitor or another display device may be provided only for research purposes. Significant features are supplied, for example, by edges, which occur reliably in the case of road vehicles. The locations of the selected edges, which define the image region to be correlated in the second processing step may be marked, for example, by means of rectangular frames in the monitor display.

[0042] In order to determine the spacing of the features

displayed on the monitor, the respective disparities are determined by comparison with the second stereo image recorded at the same time. To this end, a search is made in each rectangular image region by means of cross correlation in the corresponding image. Figure 3 shows a schematic representation to clarify the principle of the correspondence search by means of cross correlation 11.

[0043] On account of the parallel alignment of the cameras, the search region in the vertical direction may be restricted to the epipolars, the respective line in the case shown in Figure 3. In the horizontal direction, the corresponding search region is defined in the corresponding image 9, 10 in accordance with permissible disparities.

[0044] By means of using KKFMF (the local, average-free, normalized cross correlation function) as the correlation function, lightness differences in the pairs of images 9, 10, which occur for example as a result of different solar radiation or different control of the cameras, have only a slight effect on the correlation value.

[0045] The correlation coefficient from the KKFMF is calculated as follows:

$$KKFMF(x,y) = \frac{\sum_{j=0}^{n-1}\sum_{i=0}^{m-1}\left(\overline{F(i,j)}\cdot\overline{P_r(x+i,y+j)}\right)}{\sqrt{\sum_{j=0}^{n-1}\sum_{i=0}^{m-1}\overline{F(i,j)}^2\cdot\sum_{j=0}^{n-1}\sum_{i=0}^{m-1}\overline{P_r(x+i,y+j)}^2}}$$

[0046] The values $\overline{F(i,j)}$ and $\overline{P_r(x+i,y+j)}$ represent the

average-free grey values from the rectangular image regions $F(i,j)$ and $P_r(x+i,y+j)$. Because of the normalization, the results from the KKFMF move within the interval [-1, 1]. The value 1 represents agreement in pairs, -1 represents correspondingly inverse agreement.

[0047] In the last processing step in the image segmentation, combining (cluster formation) of features with similar distance values takes place (cf. Figure 1). The relative height of the clusters formed is compared with a fixed minimum height, in order to ensure an elevated object 2. In this case, elevated objects are determined through features with similar distance values, and flat objects are determined through features with similar height values.

[0048] For research purposes, the resulting clusters can be inserted as frames into a (not shown) real monitor display of the observed scene. In addition, the distances belonging to the segmented image regions may be specified in numerical values on the frames.

[0049] In addition to vehicles, other elevated objects, such as sign posts and road margins, are also segmented. In order to discard erroneous object hypotheses, the stereo-based object segmentation process within the detected image regions is followed by 2D object recognition.

[0050] In the following text, the 2D feature extraction and the vehicle recognition will now be described. These processing steps are likewise shown in Figure 1.

[0051] Road vehicles have significant features in the image plane, for example edges and corners, as well as symmetry.

These features have been determined empirically for the purpose of a search, and the recognition of road vehicles is carried out by means of direct comparison with a vehicle model. In the method shown here, a search is made in accordance with statistically verified 2D features 7, which are subsequently compared with the internal model depiction of vehicles from a neural network 8. Figure 4 shows a schematic representation to clarify the principle of the 2D feature extraction during evaluation by a neural network.

[0052] In order to determine significant and statistically verified 2D features 7 of road vehicles, a data set of 50 images, which show cars in various scenes, was used as a basis. By using the method explained below, a determination of a plurality of 9x9 large typical patterns, which often occur in the scenes used, was carried out (referred to below as comparative patterns).

[0053] The comparative patterns typically occur at specific locations on the vehicle. For example, the features may occur in the lower region of the vehicles. At these locations, most road vehicles exhibit similar structural areas. These are, for example, the shadows under the car and the corners of the tires, as well as the course of the structural areas at the head lamps.

[0054] In the segmented image regions, a search window is defined in order to calculate the features determined by means of the predefined comparative patterns. Depending on the distance of the hypothetical object, a search window of matched size is defined and correlated with the comparative patterns. The locations in the search window which exhibit a local maximum of the correlation function identify significant

features, as Figure 5 shows.

[0055] The coordinates of the extrema and the associated comparison patterns provide the input features for the feed forward network used. This has been trained for the occurrence of typical combinations of features which identify vehicles.

[0056] The real-time method according to the invention for the stereo-based tracking of objects at a considerable distance has been tried performed in real road scenes. Figure 6 represents the measured distance data from an approaching vehicle. As can be seen in Figure 6, a measurement inaccuracy of about ± 50 cm occurs at 100 meters distance.

[0057] In order to keep the determined distance data free of noise and largely free of measurement errors on account of erroneously determined correspondences, the use of a Kalman filter is suggested, which supplies more meaningful results as a result of the consideration of the measured values over time. By extending the 2D feature extraction by texture dimensions and symmetry operations, further potential is provided for improving the method presented.

[0058] In summary, it is to be recorded that, by using the method according to the invention, reliable distance determination and recognition of objects, in particular of road vehicles in front of and/or behind a travelling vehicle is possible up to a considerable distance.

Attorney Docket No. 225/50731
Marked Up Substitute Specification

Method of detecting objects in the vicinity of a road vehicle up to a considerable distance

[The invention relates to a method of detecting objects in the vicinity of a road vehicle up to a considerable distance, according to the generic features of Patent Claim 1.

In order to assist the driver of a motor vehicle in road traffic, driver assistance systems have been developed, which are suitable for detecting situations in the road traffic which are anticipated to be hazardous. Such driver assistance systems can either warn the driver, on the basis of his behaviour, or intervene in the management of the vehicle. The intention here is to increase driving safety, to relieve the driver of monotonous driving tasks and therefore for driving to become more convenient.

On account of the high requirements on the reliability of systems which increase safety, at the current time, it is predominantly convenience systems which are available on the market. Examples of this are parking aids and intelligent cruise control systems. Driver assistance systems which increase safety are intended to register the surrounding traffic situation to an ever increasing extent and to take it into account.

EP 0 558 027 B1 discloses a device for registering the distance between vehicles. In the case of this device, a pair of image sensors generates an image of an object, which is displayed to the driver. One region of this image is subdivided into windows. The distances from the driving vehicle to the object which is located in the respective window are registered. In this case, the distances are

calculated by comparing two items of image information recorded by different image sensors in different windows. On the basis of the determined distance information, the respective object is determined. A grid which divides the relevant image region is used, surrounds the object to be registered and supplies further image information. The symmetry of this image information is determined, and the existence of a vehicle travelling in front is predicted by determining a level of stability of a horizontal movement of a line of symmetry and a second level of stability of the distances over time.

This known registration device is used for the purpose of registering and recognizing vehicles located in front of the moving vehicle. The reliable recognition of objects is achieved only in the near region, however, since there the simple registration of lines of symmetry can be carried out with sufficient stability. In the remote region, this simple registration of symmetry is no longer adequate on its own because of the low resolution in the image and the resulting inaccuracy in the determination of the object.

However, high requirements have to be placed on reliable object recognition in particular, in order that the driver is not given any erroneous information, which can lead to erroneous and hazardous reactions. In the case of intelligent systems, the vehicle itself could react in a manner presenting a traffic hazard, on the basis of the erroneous information. Reliable information is imperative, for example in the case of the accurate-lane recognition of vehicles at a considerable distance, both in and counter to the actual direction of travel.

For the recognition of interesting patterns, DE 42 11 171 A1 proposes a method which applies the cross relation of small singular extracts from the entire pattern of interest by means of block-by-block progressive image recognition via a trained classification network.

DE 43 08 776 C2 discloses a device for monitoring the outer space around a vehicle which is travelling over one lane on a road, the said lane being defined by extended white lines. By means of image processing, the course of the road is determined by using three-dimensional position information from sections of the white lines. By utilizing the three-dimensional position information from the white lines, the white lines are separated from three-dimensional objects. For each section, the vertical extent of possible objects is determined. As a result, the coordinates for three-dimensional objects of interest, such as motor vehicles, motor cycles or pedestrians, can be defined in the coordinate system of the vehicle. In addition, it is possible to determine which object is concerned.

The procedure described in DE 43 08 776 C2 for monitoring the outer space around a vehicle requires a great deal of computation. It is always necessary to determine the course of the registered region of the road, in order to be able to determine the position of objects in this road course. Since only a limited amount of computing power is available in a motor vehicle, such a monitoring device is little suited to practical use. In addition, the known monitoring device is always referred to the presence of white boundary lines, which may not be found on the course of all roads.

The object of the invention is to specify a method of

detecting objects in the vicinity of a road vehicle up to a considerable distance which permits the reliable registration of objects, in particular of vehicles in front of and/or behind the road vehicle and their relevance to the situation on the basis of its position relative to the road vehicle.

According to the invention, this object is achieved by the features of Patent Claim 1. The subclaims relate to advantageous developments of the subject of the invention.

Accordingly, a method of detecting objects in the vicinity of a road vehicle up to a considerable distance is provided, in which the distance from a moving or stationary vehicle to one or more objects is calculated by distance-based image segmentation by means of stereo image processing, and characteristics of the detected objects are determined by object recognition in the segmented image regions.

Determining the characteristics of the detected objects is intended to serve to clarify their relevance to the particular vehicle and therefore contribute to the understanding of the situation.

The detection can preferably be carried out to the front or to the rear and employed, for example, to warn of jams, for distance control from the vehicle in front or for monitoring the rear space. In this case, an important point of view is that the relevance to the situation or the potential hazard of the detected objects is determined from their distance to the particular vehicle and the determined relative speed.

Instead of evaluating pairs of stereo images, which are recorded by a stereo arrangement comprising optical sensors or

cameras, in principle, even individually recorded images of different origin can be evaluated in order to determine the distance.

According to a basic idea, image regions of elevated objects and/or flat objects are determined. Elevated objects and/or flat objects are detected by combining 3D points in accordance with predetermined criteria. Combining is also designated clustering. In this case, the elevated objects are determined through features with similar distance values and flat objects are determined through features with similar height values. By means of this procedure, objects can be recognized and assessed not only reliably with regard to their distance but also with regard to specific features. Distinguishing between elevated and flat objects is therefore easily possible.

Features of similar distance values and/or similar height are combined in order to form clusters. This distinction between elevated and flat objects is very important for reliable object recognition, for example the recognition of other motor vehicles, and the distinction from road markings. Since appropriately high computing powers can be implemented nowadays in modern motor vehicles, image segmentation of this type by means of distance determination and clustering can be carried out reliably and quickly.

The detected elevated objects may be, in particular, road vehicles, signposts, bridge columns, lamp posts and so on, whereas the detected flat objects may be, in particular, road markings and boundaries such as curb stones, crash barriers and so on. In this way, for example, the position of a road vehicle on a specific road lane can be determined in a simple way.

In addition, it is advantageous to know the relative position and the relative speed of the detected objects relative to one another and to the moving vehicle, in order to determine the relevance of the detected objects to the situation. To this end, the distance measurement is evaluated, and an accurate road-lane object association is determined.

During the image segmentation, one of the recorded pairs of stereo images can be scanned for significant features of objects to be registered. The spacing of the significant features may then be determined by means of cross-relation by comparing the respective features in a stereo image from the pair of stereo images with the same, corresponding features in the other stereo image from the pair of stereo images, recorded at the same time, the disparities which occur being evaluated.

By determining the spacing of significant features in the pixel range, 3D points in the real world are determined relative to the coordinate system of the measuring device. The information obtained in this way from 3D points is therefore determined from different objects, such as vehicles, road markings, crash barriers, and so on.

For the purpose of object recognition, object hypotheses can be determined, which are verified by comparison with object models.

In this way, for the purpose of object recognition, the segmented image regions may be scanned in accordance with predetermined, statistically verified 2D features of the objects to be recognized, and the detected objects may be

compared by using a neural network for the classification of a specific object type. In this way, reliable object recognition is carried out.

The relevant objects can be followed over time and their distance and lateral position relative to the particular vehicle can be determined, in order to assess the dynamic behaviour of the relevant objects. Only with knowledge of the dynamic behaviour of the determined objects are practical reactions of the driver or of the vehicle possible. An "anticipatory" mode of driving is therefore promoted.

Furthermore, by means of this tracking, as it is known, phantom objects which occur sporadically can be suppressed, and the entire recognition performance can be increased. In this way, the number of extracted image regions to be classified in the image can be reduced, if these are checked for their local consistency by means of simple time tracking. By means of tracking the detected objects over time, the object characteristics, such as the distance, relative speed and relative acceleration, can be freed of measurement noise, for example by using a Kalman filter.

In addition to the above-described stereo-based approach, in principle object registration methods based on radar and/or infrared signals in the remote range are also possible.

Further advantages, features and details of the invention become clearer by using the following description in conjunction with the appended drawings, in which:

Fig. 1 shows a schematic representation of the method steps according to the invention;

Fig. 2 shows a schematic representation to clarify the principle of the distance determination in the case of cameras with the same focal length arranged in parallel;

Fig. 3 shows a schematic representation to clarify the principle of the correspondence search by means of cross correlation;

Fig. 4 shows a schematic representation to clarify the principle of the 2D feature extraction in the case of evaluation by a neural network according to the invention;

Fig. 5 shows a schematic representation to clarify the principle of coordinate normalization; and

Fig. 6 shows a representation of a distance profile of an approaching vehicle.

In the following text, the image segmentation by means of stereo image processing is described, during which elevated objects are detected. This is carried out through clustering individual features with similar distances. Then, a vehicle recognition method will be presented, with which road vehicles in the segmented image regions are recognized. For this purpose, features typical of vehicles are extracted and then compared with the internal vehicle model depiction from a neural network. The basic procedure is shown schematically in Figure 1.

Mono image processing is in principle also possible, given the

use of similar means and a similar procedure.

The characteristic that road vehicles are elevated by comparison with the road is used for the method of image segmentation presented here. To this end, use is made of a stereo camera system, with which it is possible to determine the distances of significant features which occur in the camera image on road vehicles. By means of this information, a statement about elevated objects is possible. The continually increasing computing power which is available in the vehicle nowadays permits real-time analysis of pairs of stereo images.

It is also possible to determine reliably on which lane a registered road vehicle is located. It is then possible to make a statement about the relevance of this registered road vehicle to the situation, on the basis of its position relative to the particular vehicle. The driver and/or the particular vehicle can then react accordingly.

Although radar systems suitable for vehicles do not offer adequate lateral resolution for lane association, infrared systems have resolution and range problems and ultrasound can generally be used for the near range, it is in principle conceivable to employ these systems instead of or in combination with stereo camera systems.

The principle of distance determination in the case of the parallel camera arrangement used is represented in Figure 2 on the basis of the pinhole camera model. The point P in the world is projected onto the sensor surfaces of each camera via the projection centres. u_0 and u_1 represent the deviation from the projection centre. Their difference

$$\Delta u = u_0 - u_1$$

is designated the disparity Δu. By means of trigonometry and the sizes of the camera arrangement (focal length f and base width b), the distance d can be calculated.

$$d = \frac{f \cdot b}{\Delta u}$$

Here, b represents the base width, f the focal length and d the distance to the point P. u_0 and u_1 are the distances of the projections of the point P onto the sensor surface.

In the first processing step in the image segmentation, a search for significant features is carried out in one of the pairs of stereo images. A corresponding display (not shown) on a monitor or another display device may be provided only for research purposes. Significant features are supplied, for example, by edges, which occur reliably in the case of road vehicles. The locations of the selected edges, which define the image region to be correlated in the second processing step may be marked, for example, by means of rectangular frames in the monitor display.

In order to determine the spacing of the features displayed on the monitor, the respective disparities are determined by comparison with the second stereo image recorded at the same time. To this end, a search is made in each rectangular image region by means of cross correlation in the corresponding image.

Figure 3 shows a schematic representation to clarify the principle of the correspondence search by means of cross

correlation.

On account of the parallel alignment of the cameras, the search region in the vertical direction may be restricted to the epipolars, the respective line in the case shown in Figure 3. In the horizontal direction, the corresponding search region is defined in the corresponding image in accordance with permissible disparities.

By means of using KKFMF (the local, average-free, normalized cross correlation function) as the correlation function, lightness differences in the pairs of images, which occur for example as a result of different solar radiation or different control of the cameras, have only a slight effect on the correlation value.

The correlation coefficient from the KKFMF is calculated as follows:

$$KKFMF(x,y) = \frac{\sum_{j=0}^{n-1} \sum_{i=0}^{m-1} \left(\overline{F(i,j)} \cdot \overline{P_r(x+i,y+j)} \right)}{\sqrt{\sum_{j=0}^{n-1} \sum_{i=0}^{m-1} \overline{F(i,j)}^2 \cdot \sum_{j=0}^{n-1} \sum_{i=0}^{m-1} \overline{P_r(x+i,y+j)}^2}}$$

The values $\overline{F(i,j)}$ and $\overline{P_r(x+i,y+j)}$ represent the average-free grey values from the rectangular image regions F(i,j) and P_r(x+i,y+j). Because of the normalization, the results from the KKFMF move within the interval [-1, 1]. The value 1 represents agreement in pairs, -1 represents correspondingly inverse agreement.

In the last processing step in the image segmentation, combining (cluster formation) of features with similar distance values takes place (cf. Figure 1). The relative height of the clusters formed is compared with a fixed minimum height, in order to ensure an elevated object. In this case, elevated objects are determined through features with similar distance values, and flat objects are determined through features with similar height values.

For research purposes, the resulting clusters can be inserted as frames into a (not shown) real monitor display of the observed scene. In addition, the distances belonging to the segmented image regions may be specified in numerical values on the frames.

In addition to vehicles, other elevated objects, such as sign posts and road margins, are also segmented. In order to discard erroneous object hypotheses, the stereo-based object segmentation process within the detected image regions is followed by 2D object recognition.

In the following text, the 2D feature extraction and the vehicle recognition will now be described. These processing steps are likewise shown in Figure 1.

Road vehicles have significant features in the image plane, for example edges and corners, as well as symmetry. These features have been determined empirically for the purpose of a search, and the recognition of road vehicles is carried out by means of direct comparison with a vehicle model. In the method shown here, a search is made in accordance with statistically verified 2D features, which are subsequently compared with the internal model depiction of vehicles from a neural network.

Figure 4 shows a schematic representation to clarify the principle of the 2D feature extraction during evaluation by a neural network.

In order to determine significant and statistically verified 2D features of road vehicles, a data set of 50 images, which show cars in various scenes, was used as a basis. By using the method explained below, a determination of a plurality of 9x9 large typical patterns, which often occur in the scenes used, was carried out (referred to below as comparative patterns).

The comparative patterns typically occur at specific locations on the vehicle. For example, the features may occur in the lower region of the vehicles. At these locations, most road vehicles exhibit similar structural areas. These are, for example, the shadows under the car and the corners of the tyres, as well as the course of the structural areas at the head lamps.

In the segmented image regions, a search window is defined in order to calculate the features determined by means of the predefined comparative patterns. Depending on the distance of the hypothetical object, a search window of matched size is defined and correlated with the comparative patterns. The locations in the search window which exhibit a local maximum of the correlation function identify significant features, as Figure 5 shows.

The coordinates of the extrema and the associated comparison patterns provide the input features for the feed forward network used. This has been trained for the occurrence of typical combinations of features which identify vehicles.

The real-time method according to the invention for the stereo-based tracking of objects at a considerable distance has been tried out in real road scenes. Figure 6 represents the measured distance data from an approaching vehicle. As can be seen in Figure 6, a measurement inaccuracy of about ± 50 cm occurs at 100 metres distance.

In order to keep the determined distance data free of noise and largely free of measurement errors on account of erroneously determined correspondences, the use of a Kalman filter is suggested, which supplies more meaningful results as a result of the consideration of the measured values over time. By extending the 2D feature extraction by texture dimensions and symmetry operations, further potential is provided for improving the method presented.

In summary, it is to be recorded that, by using the method according to the invention, reliable distance determination and recognition of objects, in particular of road vehicles in front of and/or behind a travelling vehicle,is possible up to a considerable distance.]

BACKGROUND AND SUMMARY OF THE INVENTION

The invention relates to a method of detecting objects in the vicinity of a road vehicle up to a considerable distance, in which the distance from a moving or stationary vehicle to one or more objects is calculated by distance-based image segmentation using stereo image processing, and characteristics of the detected objects are determined by object recognition in the segmented image regions. Image regions of elevated objects and/or flat objects are determined and the elevated objects and/or flat objects are detected by combining (clustering) 3D points in accordance with

predetermined criteria. The elevated objects are determined through features with similar distance values and the flat objects are determined through features with similar height values. The relevant objects are followed over time (tracking) and their distance and lateral position relative to the particular vehicle is determined in order to assess the dynamic behavior of the relevant objects.

In order to assist the driver of a motor vehicle in road traffic, driver assistance systems have been developed, which are suitable for detecting situations in the road traffic which are anticipated to be hazardous. Such driver assistance systems can either warn the driver, on the basis of his behavior, or intervene in the management of the vehicle. The intention here is to increase driving safety, to relieve the driver of monotonous driving tasks and, therefore, for driving to become more convenient.

On account of the high requirements on the reliability of systems which increase safety, at the current time, it is predominantly convenience systems which are available on the market. Examples of this are parking aids and intelligent cruise control systems. Driver assistance systems which increase safety are intended to register the surrounding traffic situation to an ever increasing extent and to take it into account.

EP 0 558 027 B1 discloses a device for registering the distance between vehicles. In the case of this device, a pair of image sensors generates an image of an object, which is displayed to the driver. One region of this image is subdivided into windows. The distances from the driving vehicle to the object, which is located in the respective

window, are registered. In this case, the distances are calculated by comparing two items of image information recorded by different image sensors in different windows. On the basis of the determined distance information, the respective object is determined. A grid which divides the relevant image region is used. The grid surrounds the object to be registered and supplies further image information. The symmetry of this image information is determined, and the existence of a vehicle travelling in front is predicted by determining a level of stability of a horizontal movement of a line of symmetry and a second level of stability of the distances over time.

This known registration device is used for the purpose of registering and recognizing vehicles located in front of the moving vehicle. The reliable recognition of objects is achieved only in the near region, however, since there the simple registration of lines of symmetry can be carried out with sufficient stability. In the remote region, this simple registration of symmetry is no longer adequate on its own because of the low resolution in the image and the resulting inaccuracy in the determination of the object.

However, high requirements have to be placed on reliable object recognition in particular, in order that the driver is not given any erroneous information, which can lead to erroneous and hazardous reactions. In the case of intelligent systems, the vehicle itself could react in a manner presenting a traffic hazard, on the basis of the erroneous information. Reliable information is imperative, for example in accurate-lane recognition of vehicles at a considerable distance, both in and counter to the actual direction of travel.

For the recognition of interesting patterns, DE 42 11 171 A1 proposes a method which applies the cross relation of small singular extracts from the entire pattern of interest by means of block-by-block progressive image recognition via a trained classification network.

DE 43 08 776 C2 discloses a device for monitoring the outer space around a vehicle, which is travelling over one lane on a road. The lane is defined by extended white lines. By means of image processing, the course of the road is determined by using three-dimensional position information from sections of the white lines. By utilizing the three-dimensional position information from the white lines, the white lines are separated from three-dimensional objects. For each section, the vertical extent of possible objects is determined. As a result, the coordinates for three-dimensional objects of interest, such as motor vehicles, motor cycles or pedestrians, can be defined in the coordinate system of the vehicle. In addition, it is possible to determine which object is concerned.

The procedure described in DE 43 08 776 C2 for monitoring the outer space around a vehicle requires a great deal of computation. It is always necessary to determine the course of the registered region of the road, in order to be able to determine the position of objects in this road course. Since only a limited amount of computing power is available in a motor vehicle, such a monitoring device is ill-suited to practical use. In addition, the known monitoring device is always referred to the presence of white boundary lines, which may not be found on the course of all roads.

EP-A-0 874 331 discloses the practice of dividing up a

distance image into regions in the lateral direction away from the vehicle. In this case, a histogram relating to the distance values in the individual regions is drawn up, in order to determine the distances of individual objects from these histograms. The possibility of a collision or contact with objects or other vehicles on the roadway is determined from the position and size of the objects or vehicles. The relative speed of the objects in relation to the particular vehicle is determined by tracking the objects. A reliable statement relating to the relevance of the objects to the situation is possible only after a very computationally intensive procedure, which calls a practical application in road vehicles into question.

The object of the invention is to specify a method of detecting objects in the vicinity of a road vehicle up to a considerable distance which permits the reliable registration of objects, in particular of vehicles in front of and/or behind the road vehicle and their relevance to the situation on the basis of its position relative to the road vehicle.

According to the invention, this object is achieved by determining for the purpose of object recognition, object hypotheses, which are verified by comparison with object models. Segmented image regions are scanned in accordance with predetermined, statistically verified 2D features of the objects to be recognized. The detected objects are compared by using a neural network for the classification of a specific object type. The subclaims relate to advantageous developments of the subject of the invention.

Accordingly, a method of detecting objects in the vicinity of a road vehicle up to a considerable distance is

provided, in which the distance from a moving or stationary vehicle to one or more objects is calculated by distance-based image segmentation by means of stereo image processing, and characteristics of the detected objects are determined by object recognition in the segmented image regions.

Determining the characteristics of the detected objects is intended to serve to clarify their relevance to the particular vehicle and therefore contribute to the understanding of the situation.

The detection can preferably be carried out to the front or to the rear and employed, for example, to warn of traffic jams, for distance control from the vehicle in front or for monitoring the rear space. In this case, an important point of view is that the relevance to the situation or the potential hazard of the detected objects is determined from their distance to the particular vehicle and the determined relative speed.

Instead of evaluating pairs of stereo images, which are recorded by a stereo arrangement comprising optical sensors or cameras, in principle, even individually recorded images of different origin can be evaluated in order to determine the distance.

Image regions of elevated objects and/or flat objects are determined. Elevated objects and/or flat objects are detected by combining 3D points in accordance with predetermined criteria. Combining is also designated clustering. In this case, the elevated objects are determined through features with similar distance values and flat objects are determined through features with similar height values. By means of this

procedure, objects can be recognized and assessed not only reliably with regard to their distance but also with regard to specific features. Distinguishing between elevated and flat objects is therefore easily possible.

Features of similar distance values and/or similar height are combined in order to form clusters. This distinction between elevated and flat objects is very important for reliable object recognition, for example the recognition of other motor vehicles, and the distinction from road markings. Since appropriately high computing powers can be implemented nowadays in modern motor vehicles, image segmentation of this type by means of distance determination and clustering can be carried out reliably and quickly.

The relevant objects are followed over time and their distance and lateral position relative to the particular vehicle are determined, in order to assess the dynamic behavior of the relevant objects. Only with knowledge of the dynamic behavior of the determined objects are practical reactions of the driver or of the vehicle possible. An "anticipatory" mode of driving is therefore promoted.

Furthermore, by means of this tracking, as it is known, phantom objects which occur sporadically can be suppressed, and the entire recognition performance can be increased. In this way, the number of extracted image regions to be classified in the image can be reduced, if these are checked for their local consistency by means of simple time tracking. By means of tracking the detected objects over time, the object characteristics, such as the distance, relative speed and relative acceleration, can be freed of measurement noise, for example by using a Kalman filter.

For the purpose of object recognition, object hypotheses are determined, which are verified by comparison with object models.

In this way, for the purpose of object recognition, the segmented image regions may be scanned in accordance with predetermined, statistically verified 2D features of the objects to be recognized, and the detected objects may be compared by using a neural network for the classification of a specific object type. In this way, reliable object recognition is carried out.

The detected elevated objects may be, in particular, road vehicles, signposts, bridge columns, lamp posts and so on, whereas the detected flat objects may be, in particular, road markings and boundaries such as curb stones, crash barriers and so on. In this way, for example, the position of a road vehicle on a specific road lane can be determined in a simple way.

In addition, it is advantageous to know the relative position and the relative speed of the detected objects relative to one another and to the moving vehicle, in order to determine the relevance of the detected objects to the situation. To this end, the distance measurement is evaluated, and an accurate road-lane object association is determined.

During the image segmentation, one of the recorded pairs of stereo images can be scanned for significant features of objects to be registered. The spacing of the significant features may then be determined by means of cross-relation by comparing the respective features in a stereo image from the

pair of stereo images with the same, corresponding features in the other stereo image from the pair of stereo images, recorded at the same time. The disparities which occur are evaluated.

By determining the spacing of significant features in the pixel range, 3D points in the real world are determined relative to the coordinate system of the measuring device. The information obtained in this way from 3D points is therefore determined from different objects, such as vehicles, road markings, crash barriers, and so on.

In addition to the above-described stereo-based approach, in principle object registration methods based on radar and/or infrared signals in the remote range are also possible.

BRIEF DESCRIPTION OF THE DRAWINGS

Further advantages, features and details of the invention become clearer by using the following description in conjunction with the appended drawings, in which:

Fig. 1 shows a schematic representation of the method steps according to the invention;

Fig. 2 shows a schematic representation to clarify the principle of the distance determination in the case of cameras with the same focal length arranged in parallel;

Fig. 3 shows a schematic representation to clarify the principle of the correspondence search by means of cross correlation;

Fig. 4 shows a schematic representation to clarify the

principle of the 2D feature extraction in the case of evaluation by a neural network according to the invention;

Fig. 5 shows a schematic representation to clarify the principle of coordinate normalization; and

Fig. 6 shows a representation of a distance profile of an approaching vehicle.

DETAILED DESCRIPTION OF THE DRAWINGS

In the following text, the image segmentation 1 by means of stereo image processing is described, during which elevated objects 2 are detected. This is carried out through clustering 3 individual features with similar distances. Then, a vehicle recognition method 5, 6 will be presented, with which road vehicles in the segmented image regions are recognized. For this purpose, features typical of vehicles are extracted 6 and then compared with the internal vehicle model depiction 5 from a neural network 8. The basic procedure is shown schematically in Figure 1.

Mono image processing is in principle also possible, given the use of similar means and a similar procedure.

The characteristic that road vehicles are elevated by comparison with the road is used for the method of image segmentation presented here. To this end, use is made of a stereo camera system, with which it is possible to determine the distances of significant features which occur in the camera image on road vehicles. By means of this information, a statement about elevated objects 4 is possible. The continually increasing computing power, which is available in the vehicle nowadays, permits real-time analysis of pairs of

stereo images.

It is also possible to determine reliably on which lane a registered road vehicle is located. It is then possible to make a statement about the relevance of this registered road vehicle to the situation, on the basis of its position relative to the particular vehicle. The driver and/or the particular vehicle can then react accordingly.

Although radar systems suitable for vehicles do not offer adequate lateral resolution for lane association, infrared systems have resolution and range problems and ultrasound can generally be used for the near range, it is in principle conceivable to employ these systems instead of or in combination with stereo camera systems.

The principle of distance determination in the case of the parallel camera arrangement used is represented in Figure 2 on the basis of the pinhole camera model. The point P in the world (camera's field of view) is projected onto the sensor surfaces of each camera via the projection centers. u_0 and u_1 represent the deviation from the projection center. Their difference

$$\Delta u = u_0 - u_1$$

is designated the disparity Δu. By means of trigonometry and the sizes of the camera arrangement (focal length f and base width b), the distance d can be calculated.

$$d = \frac{f \cdot b}{\Delta u}$$

Here, *b* represents the base width, *f* the focal length and *d* the distance to the point P. u_0 and u_1 are the distances of the projections of the point P onto the sensor surface.

In the first processing step in the image segmentation, a search for significant features is carried out in one of the pairs of stereo images. A corresponding display (not shown) on a monitor or another display device may be provided only for research purposes. Significant features are supplied, for example, by edges, which occur reliably in the case of road vehicles. The locations of the selected edges, which define the image region to be correlated in the second processing step may be marked, for example, by means of rectangular frames in the monitor display.

In order to determine the spacing of the features displayed on the monitor, the respective disparities are determined by comparison with the second stereo image recorded at the same time. To this end, a search is made in each rectangular image region by means of cross correlation in the corresponding image. Figure 3 shows a schematic representation to clarify the principle of the correspondence search by means of cross correlation 11.

On account of the parallel alignment of the cameras, the search region in the vertical direction may be restricted to the epipolars, the respective line in the case shown in Figure 3. In the horizontal direction, the corresponding search region is defined in the corresponding image 9, 10 in accordance with permissible disparities.

By means of using KKFMF (the local, average-free, normalized cross correlation function) as the correlation

function, lightness differences in the pairs of images 9, 10, which occur for example as a result of different solar radiation or different control of the cameras, have only a slight effect on the correlation value.

The correlation coefficient from the KKFMF is calculated as follows:

$$KKFMF(x,y)=\frac{\sum_{j=0}^{n-1}\sum_{i=0}^{m-1}\left(\overline{F(i,j)}\cdot\overline{P_r(x+i,y+j)}\right)}{\sqrt{\sum_{j=0}^{n-1}\sum_{i=0}^{m-1}\overline{F(i,j)}^2\cdot\sum_{j=0}^{n-1}\sum_{i=0}^{m-1}\overline{P_r(x+i,y+j)}^2}}$$

The values $\overline{F(i,j)}$ and $\overline{P_r(x+i,y+j)}$ represent the average-free grey values from the rectangular image regions F(i,j) and $P_r(x+i,y+j)$. Because of the normalization, the results from the KKFMF move within the interval [-1, 1]. The value 1 represents agreement in pairs, -1 represents correspondingly inverse agreement.

In the last processing step in the image segmentation, combining (cluster formation) of features with similar distance values takes place (cf. Figure 1). The relative height of the clusters formed is compared with a fixed minimum height, in order to ensure an elevated object 2. In this case, elevated objects are determined through features with similar distance values, and flat objects are determined through features with similar height values.

For research purposes, the resulting clusters can be inserted as frames into a (not shown) real monitor display of

the observed scene. In addition, the distances belonging to the segmented image regions may be specified in numerical values on the frames.

In addition to vehicles, other elevated objects, such as sign posts and road margins, are also segmented. In order to discard erroneous object hypotheses, the stereo-based object segmentation process within the detected image regions is followed by 2D object recognition.

In the following text, the 2D feature extraction and the vehicle recognition will now be described. These processing steps are likewise shown in Figure 1.

Road vehicles have significant features in the image plane, for example edges and corners, as well as symmetry. These features have been determined empirically for the purpose of a search, and the recognition of road vehicles is carried out by means of direct comparison with a vehicle model. In the method shown here, a search is made in accordance with statistically verified 2D features 7, which are subsequently compared with the internal model depiction of vehicles from a neural network 8. Figure 4 shows a schematic representation to clarify the principle of the 2D feature extraction during evaluation by a neural network.

In order to determine significant and statistically verified 2D features 7 of road vehicles, a data set of 50 images, which show cars in various scenes, was used as a basis. By using the method explained below, a determination of a plurality of 9x9 large typical patterns, which often occur in the scenes used, was carried out (referred to below as comparative patterns).

The comparative patterns typically occur at specific locations on the vehicle. For example, the features may occur in the lower region of the vehicles. At these locations, most road vehicles exhibit similar structural areas. These are, for example, the shadows under the car and the corners of the tires, as well as the course of the structural areas at the head lamps.

In the segmented image regions, a search window is defined in order to calculate the features determined by means of the predefined comparative patterns. Depending on the distance of the hypothetical object, a search window of matched size is defined and correlated with the comparative patterns. The locations in the search window which exhibit a local maximum of the correlation function identify significant features, as Figure 5 shows.

The coordinates of the extrema and the associated comparison patterns provide the input features for the feed forward network used. This has been trained for the occurrence of typical combinations of features which identify vehicles.

The real-time method according to the invention for the stereo-based tracking of objects at a considerable distance has been tried performed in real road scenes. Figure 6 represents the measured distance data from an approaching vehicle. As can be seen in Figure 6, a measurement inaccuracy of about ± 50 cm occurs at 100 meters distance.

In order to keep the determined distance data free of noise and largely free of measurement errors on account of erroneously determined correspondences, the use of a Kalman

filter is suggested, which supplies more meaningful results as a result of the consideration of the measured values over time. By extending the 2D feature extraction by texture dimensions and symmetry operations, further potential is provided for improving the method presented.

In summary, it is to be recorded that, by using the method according to the invention, reliable distance determination and recognition of objects, in particular of road vehicles in front of and/or behind a travelling vehicle is possible up to a considerable distance.

New description

The invention relates to a method of detecting objects in the vicinity of a road vehicle up to a considerable distance, according to the generic features of Patent Claim 1.

In order to assist the driver of a motor vehicle in road traffic, driver assistance systems have been developed, which are suitable for detecting situations in the road traffic which are anticipated to be hazardous. Such driver assistance systems can either warn the driver, on the basis of his behaviour, or intervene in the management of the vehicle. The intention here is to increase driving safety, to relieve the driver of monotonous driving tasks and therefore for driving to become more convenient.

On account of the high requirements on the reliability of systems which increase safety, at the current time, it is predominantly convenience systems which are available on the market. Examples of this are parking aids and intelligent cruise control systems. Driver assistance systems which increase safety are intended to register the surrounding traffic situation to an ever increasing extent and to take it into account.

EP 0 558 027 B1 discloses a device for registering the distance between vehicles. In the case of this device, a pair of image sensors generates an image of an object, which is displayed to the driver. One region of this image is subdivided into windows. The distances from the driving vehicle to the object which is located in the respective window are registered. In this case, the distances are calculated by comparing two items of image information recorded by different image sensors in different windows. On the basis of the determined

distance information, the respective object is determined. A grid which divides the relevant image region is used, surrounds the object to be registered and supplies further image information. The symmetry of this image information is determined, and the existence of a vehicle travelling in front is predicted by determining a level of stability of a horizontal movement of a line of symmetry and a second level of stability of the distances over time.

This known registration device is used for the purpose of registering and recognizing vehicles located in front of the moving vehicle. The reliable recognition of objects is achieved only in the near region, however, since there the simple registration of lines of symmetry can be carried out with sufficient stability. In the remote region, this simple registration of symmetry is no longer adequate on its own because of the low resolution in the image and the resulting inaccuracy in the determination of the object.

However, high requirements have to be placed on reliable object recognition in particular, in order that the driver is not given any erroneous information, which can lead to erroneous and hazardous reactions. In the case of intelligent systems, the vehicle itself could react in a manner presenting a traffic hazard, on the basis of the erroneous information. Reliable information is imperative, for example in the case of the accurate-lane recognition of vehicles at a considerable distance, both in and counter to the actual direction of travel.

For the recognition of interesting patterns, DE 42 11 171 A1 proposes a method which applies the cross relation of small singular extracts from the

entire pattern of interest by means of block-by-block progressive image recognition via a trained classification network.

DE 43 08 776 C2 discloses a device for monitoring the outer space around a vehicle which is travelling over one lane on a road, the said lane being defined by extended white lines. By means of image processing, the course of the road is determined by using three-dimensional position information from sections of the white lines. By utilizing the three-dimensional position information from the white lines, the white lines are separated from three-dimensional objects. For each section, the vertical extent of possible objects is determined. As a result, the coordinates for three-dimensional objects of interest, such as motor vehicles, motor cycles or pedestrians, can be defined in the coordinate system of the vehicle. In addition, it is possible to determine which object is concerned.

The procedure described in DE 43 08 776 C2 for monitoring the outer space around a vehicle requires a great deal of computation. It is always necessary to determine the course of the registered region of the road, in order to be able to determine the position of objects in this road course. Since only a limited amount of computing power is available in a motor vehicle, such a monitoring device is little suited to practical use. In addition, the known monitoring device is always referred to the presence of white boundary lines, which may not be found on the course of all roads.

EP-A-0 874 331 discloses the practice of dividing up a distance image into regions in the lateral direction away from the vehicle. In this case, a histogram relating to the distance values in the individual

regions is drawn up, in order to determine the distances of individual objects from these histograms. The possibility of a collision or contact with objects or other vehicles on the roadway is determined from the position and size of the objects or vehicles. The relative speed of the objects in relation to the particular vehicle is determined by tracking the objects. A reliable statement relating to the relevance of the objects to the situation is possible only after a very computationally intensive procedure, which calls a practical application in road vehicles into question.

The object of the invention is to specify a method of detecting objects in the vicinity of a road vehicle up to a considerable distance which permits the reliable registration of objects, in particular of vehicles in front of and/or behind the road vehicle and their relevance to the situation on the basis of its position relative to the road vehicle.

According to the invention, this object is achieved by the features of Patent Claim 1. The subclaims relate to advantageous developments of the subject of the invention.

Accordingly, a method of detecting objects in the vicinity of a road vehicle up to a considerable distance is provided, in which the distance from a moving or stationary vehicle to one or more objects is calculated by distance-based image segmentation by means of stereo image processing, and characteristics of the detected objects are determined by object recognition in the segmented image regions.

Determining the characteristics of the detected objects is intended to serve to clarify their relevance to the

particular vehicle and therefore contribute to the understanding of the situation.

The detection can preferably be carried out to the front or to the rear and employed, for example, to warn of jams, for distance control from the vehicle in front or for monitoring the rear space. In this case, an important point of view is that the relevance to the situation or the potential hazard of the detected objects is determined from their distance to the particular vehicle and the determined relative speed.

Instead of evaluating pairs of stereo images, which are recorded by a stereo arrangement comprising optical sensors or cameras, in principle, even individually recorded images of different origin can be evaluated in order to determine the distance.

Image regions of elevated objects and/or flat objects are determined. Elevated objects and/or flat objects are detected by combining 3D points in accordance with predetermined criteria. Combining is also designated clustering. In this case, the elevated objects are determined through features with similar distance values and flat objects are determined through features with similar height values. By means of this procedure, objects can be recognized and assessed not only reliably with regard to their distance but also with regard to specific features. Distinguishing between elevated and flat objects is therefore easily possible.

Features of similar distance values and/or similar height are combined in order to form clusters. This distinction between elevated and flat objects is very important for reliable object recognition, for example the recognition of other motor vehicles, and the distinction from road markings. Since appropriately

high computing powers can be implemented nowadays in modern motor vehicles, image segmentation of this type by means of distance determination and clustering can be carried out reliably and quickly.

The relevant objects are followed over time and their distance and lateral position relative to the particular vehicle are determined, in order to assess the dynamic behaviour of the relevant objects. Only with knowledge of the dynamic behaviour of the determined objects are practical reactions of the driver or of the vehicle possible. An "anticipatory" mode of driving is therefore promoted.

Furthermore, by means of this tracking, as it is known, phantom objects which occur sporadically can be suppressed, and the entire recognition performance can be increased. In this way, the number of extracted image regions to be classified in the image can be reduced, if these are checked for their local consistency by means of simple time tracking. By means of tracking the detected objects over time, the object characteristics, such as the distance, relative speed and relative acceleration, can be freed of measurement noise, for example by using a Kalman filter.

For the purpose of object recognition, object hypotheses are determined, which are verified by comparison with object models.

In this way, for the purpose of object recognition, the segmented image regions may be scanned in accordance with predetermined, statistically verified 2D features of the objects to be recognized, and the detected objects may be compared by using a neural network for the classification of a specific object type. In this way, reliable object recognition is carried out.

The detected elevated objects may be, in particular, road vehicles, signposts, bridge columns, lamp posts and so on, whereas the detected flat objects may be, in particular, road markings and boundaries such as curb stones, crash barriers and so on. In this way, for example, the position of a road vehicle on a specific road lane can be determined in a simple way.

In addition, it is advantageous to know the relative position and the relative speed of the detected objects relative to one another and to the moving vehicle, in order to determine the relevance of the detected objects to the situation. To this end, the distance measurement is evaluated, and an accurate road-lane object association is determined.

During the image segmentation, one of the recorded pairs of stereo images can be scanned for significant features of objects to be registered. The spacing of the significant features may then be determined by means of cross-relation by comparing the respective features in a stereo image from the pair of stereo images with the same, corresponding features in the other stereo image from the pair of stereo images, recorded at the same time, the disparities which occur being evaluated.

By determining the spacing of significant features in the pixel range, 3D points in the real world are determined relative to the coordinate system of the measuring device. The information obtained in this way from 3D points is therefore determined from different objects, such as vehicles, road markings, crash barriers, and so on.

In addition to the above-described stereo-based approach, in principle object registration methods

based on radar and/or infrared signals in the remote range are also possible.

Further advantages, features and details of the invention become clearer by using the following description in conjunction with the appended drawings, in which:

Fig. 1 shows a schematic representation of the method steps according to the invention;

Fig. 2 shows a schematic representation to clarify the principle of the distance determination in the case of cameras with the same focal length arranged in parallel;

Fig. 3 shows a schematic representation to clarify the principle of the correspondence search by means of cross correlation;

Fig. 4 shows a schematic representation to clarify the principle of the 2D feature extraction in the case of evaluation by a neural network according to the invention;

Fig. 5 shows a schematic representation to clarify the principle of coordinate normalization; and

Fig. 6 shows a representation of a distance profile of an approaching vehicle.

In the following text, the image segmentation 1 by means of stereo image processing is described, during which elevated objects 2 are detected. This is carried out through clustering 3 individual features with similar distances. Then, a vehicle recognition method 5, 6 will be presented, with which road vehicles in the

segmented image regions are recognized. For this purpose, features typical of vehicles are extracted 6 and then compared with the internal vehicle model depiction 5 from a neural network 8. The basic procedure is shown schematically in Figure 1.

Mono image processing is in principle also possible, given the use of similar means and a similar procedure.

The characteristic that road vehicles are elevated by comparison with the road is used for the method of image segmentation presented here. To this end, use is made of a stereo camera system, with which it is possible to determine the distances of significant features which occur in the camera image on road vehicles. By means of this information, a statement about elevated objects 4 is possible. The continually increasing computing power which is available in the vehicle nowadays permits real-time analysis of pairs of stereo images.

It is also possible to determine reliably on which lane a registered road vehicle is located. It is then possible to make a statement about the relevance of this registered road vehicle to the situation, on the basis of its position relative to the particular vehicle. The driver and/or the particular vehicle can then react accordingly.

Although radar systems suitable for vehicles do not offer adequate lateral resolution for lane association, infrared systems have resolution and range problems and ultrasound can generally be used for the near range, it is in principle conceivable to employ these systems instead of or in combination with stereo camera systems.

The principle of distance determination in the case of the parallel camera arrangement used is represented in Figure 2 on the basis of the pinhole camera model. The point P in the world is projected onto the sensor surfaces of each camera via the projection centres. u_0 and u_1 represent the deviation from the projection centre. Their difference

$$\Delta u = u_0 - u_1$$

is designated the disparity Δu. By means of trigonometry and the sizes of the camera arrangement (focal length f and base width b), the distance d can be calculated.

$$d = \frac{f \cdot b}{\Delta u}$$

Here, b represents the base width, f the focal length and d the distance to the point P. u_0 and u_1 are the distances of the projections of the point P onto the sensor surface.

In the first processing step in the image segmentation, a search for significant features is carried out in one of the pairs of stereo images. A corresponding display (not shown) on a monitor or another display device may be provided only for research purposes. Significant features are supplied, for example, by edges, which occur reliably in the case of road vehicles. The locations of the selected edges, which define the image region to be correlated in the second processing step may be marked, for example, by means of rectangular frames in the monitor display.

In order to determine the spacing of the features displayed on the monitor, the respective disparities

are determined by comparison with the second stereo image recorded at the same time. To this end, a search is made in each rectangular image region by means of cross correlation in the corresponding image. Figure 3 shows a schematic representation to clarify the principle of the correspondence search by means of cross correlation 11.

On account of the parallel alignment of the cameras, the search region in the vertical direction may be restricted to the epipolars, the respective line in the case shown in Figure 3. In the horizontal direction, the corresponding search region is defined in the corresponding image 9, 10 in accordance with permissible disparities.

By means of using KKFMF (the local, average-free, normalized cross correlation function) as the correlation function, lightness differences in the pairs of images 9, 10, which occur for example as a result of different solar radiation or different control of the cameras, have only a slight effect on the correlation value.

The correlation coefficient from the KKFMF is calculated as follows:

$$KKFMF(x,y) = \frac{\sum_{j=0}^{n-1} \sum_{i=0}^{m-1} \left(\overline{F(i,j)} \cdot \overline{P_r(x+i,y+j)} \right)}{\sqrt{\sum_{j=0}^{n-1} \sum_{i=0}^{m-1} \overline{F(i,j)}^2 \cdot \sum_{j=0}^{n-1} \sum_{i=0}^{m-1} \overline{P_r(x+i,y+j)}^2}}$$

The values $\overline{F(i,j)}$ and $\overline{P_r(x+i,y+j)}$ represent the average-free grey values from the rectangular image regions $F(i,j)$ and $P_r(x+i,y+j)$. Because of the normalization, the results from the KKFMF move within

the interval [-1, 1]. The value 1 represents agreement in pairs, -1 represents correspondingly inverse agreement.

In the last processing step in the image segmentation, combining (cluster formation) of features with similar distance values takes place (cf. Figure 1). The relative height of the clusters formed is compared with a fixed minimum height, in order to ensure an elevated object 2. In this case,elevated objects are determined through features with similar distance values, and flat objects are determined through features with similar height values.

For research purposes, the resulting clusters can be inserted as frames into a (not shown) real monitor display of the observed scene. In addition, the distances belonging to the segmented image regions may be specified in numerical values on the frames.

In addition to vehicles, other elevated objects, such as sign posts and road margins, are also segmented. In order to discard erroneous object hypotheses, the stereo-based object segmentation process within the detected image regions is followed by 2D object recognition.

In the following text, the 2D feature extraction and the vehicle recognition will now be described. These processing steps are likewise shown in Figure 1.

Road vehicles have significant features in the image plane, for example edges and corners, as well as symmetry. These features have been determined empirically for the purpose of a search, and the recognition of road vehicles is carried out by means of direct comparison with a vehicle model. In the method

shown here, a search is made in accordance with statistically verified 2D features 7, which are subsequently compared with the internal model depiction of vehicles from a neural network 8. Figure 4 shows a schematic representation to clarify the principle of the 2D feature extraction during evaluation by a neural network.

In order to determine significant and statistically verified 2D features 7 of road vehicles, a data set of 50 images, which show cars in various scenes, was used as a basis. By using the method explained below, a determination of a plurality of 9x9 large typical patterns, which often occur in the scenes used, was carried out (referred to below as comparative patterns).

The comparative patterns typically occur at specific locations on the vehicle. For example, the features may occur in the lower region of the vehicles. At these locations, most road vehicles exhibit similar structural areas. These are, for example, the shadows under the car and the corners of the tyres, as well as the course of the structural areas at the head lamps.

In the segmented image regions, a search window is defined in order to calculate the features determined by means of the predefined comparative patterns. Depending on the distance of the hypothetical object, a search window of matched size is defined and correlated with the comparative patterns. The locations in the search window which exhibit a local maximum of the correlation function identify significant features, as Figure 5 shows.

The coordinates of the extrema and the associated comparison patterns provide the input features for the

feed forward network used. This has been trained for the occurrence of typical combinations of features which identify vehicles.

The real-time method according to the invention for the stereo-based tracking of objects at a considerable distance has been tried out in real road scenes. Figure 6 represents the measured distance data from an approaching vehicle. As can be seen in Figure 6, a measurement inaccuracy of about ± 50 cm occurs at 100 metres distance.

In order to keep the determined distance data free of noise and largely free of measurement errors on account of erroneously determined correspondences, the use of a Kalman filter is suggested, which supplies more meaningful results as a result of the consideration of the measured values over time. By extending the 2D feature extraction by texture dimensions and symmetry operations, further potential is provided for improving the method presented.

In summary, it is to be recorded that, by using the method according to the invention, reliable distance determination and recognition of objects, in particular of road vehicles in front of and/or behind a travelling vehicle is possible up to a considerable distance.

New Patent Claims

1. Method of detecting objects in the vicinity of a road vehicle up to a considerable distance, in which the distance from a moving or stationary vehicle to one or more objects is calculated by distance-based image segmentation (1) by means of stereo image processing, and characteristics of the detected objects are determined by object recognition in the segmented image regions,
image regions of elevated objects and/or flat objects being determined (2), and
elevated objects and/or flat objects being detected by combining (clustering) (3) 3D points in accordance with predetermined criteria, elevated objects being determined through features with similar distance values and flat objects being determined through features with similar height values, and
the relevant objects (4) being followed over time (tracking) and their distance and lateral position relative to the particular vehicle being determined, in order to assess the dynamic behaviour of the relevant objects,
characterized in that
for the purpose of object recognition, object hypotheses are determined, which are verified by comparison with object models (5),
the segmented image regions being scanned in accordance with predetermined, statistically verified 2D features of the objects to be recognized (6, 7), and
the detected objects being compared by using a neural network (8) for the classification of a specific object type.

2. Method according to Claim 1, characterized in that the detected elevated objects (4) are in particular road vehicles and/or the detected flat objects are in particular road markings and boundaries.

3. Method according to Claim 1 or 2, characterized in that the relative position and the relative speed of the detected objects relative to one another and to the moving vehicle are determined by evaluating the distance measurement, in order to determine an accurate road-lane object association and/or the relevance of the detected objects to the situation.

4. Method according to one of Claims 1 to 3, characterized in that
one of the recorded pairs of stereo images (9, 10) is scanned for significant features of objects to be registered, and
the spacing of the significant features is determined by comparing the respective features in a stereo image from the pair of stereo images with the same, corresponding features in the other stereo image from the pair of stereo images (9, 10), recorded at the same time, the disparities which occur being evaluated by means of cross correlation (11).

5. Method according to one of Claims 1 to 4, characterized in that by determining the spacing of significant features in the pixel range, 3D points in the real world are determined relative to the coordinate system of the measuring device.

6. Method according to one of Claims 1 to 5, characterized in that the objects are detected by

means of radar and/or infrared sensors and/or a stereo or mono arrangement of optical sensors or cameras.

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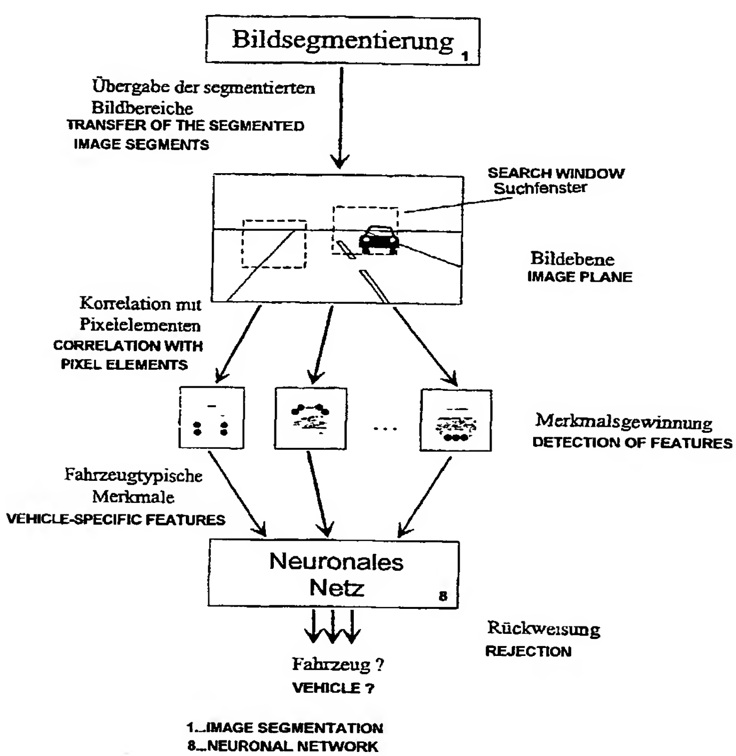
(81) Bestimmungsstaaten *(national)*: JP, US.

[Fortsetzung auf der nächsten Seite]

(54) Title: METHOD OF DETECTING OBJECTS WITHIN A WIDE RANGE OF A ROAD VEHICLE

(54) Bezeichnung: VERFAHREN ZUR DETEKTION VON OBJEKTEN IM UMFELD EINES STRASSENFAHRZEUGS BIS IN GROSSE ENTFERNUNG



(57) Abstract: The invention relates to a method of detecting objects within a wide range of a road vehicle. According to said method, the distance between a moving or stationary vehicle and one or more objects is calculated by distance-based image segmentation using stereoscopic image processing techniques and the properties of the detected objects are determined by object recognition in the segmented image areas. Image areas of three-dimensional and/or flat objects are detected and said three-dimensional and/or flat objects are detected by clustering 3D pixels according to defined criteria. Three-dimensional objects are determined by features with similar distance values and flat objects by features with similar height values.

(57) Zusammenfassung: Die Erfindung betrifft ein Verfahren zur Detektion von Objekten im Umfeld eines Strassenfahrzeugs bis in grosse Entfernung, bei welchem die Entfernung eines bewegten oder stehenden Fahrzeugs zu einem oder mehreren Objekten durch entfernungsbasierte Bildesegmentierung mittels Stereobildverarbeitung berechnet wird und Eigenschaften der detektierten Objekte durch Objekterkennung in den segmentierten Bildbereichen

[Fortsetzung auf der nächsten Seite]

WO 00/77736 A1

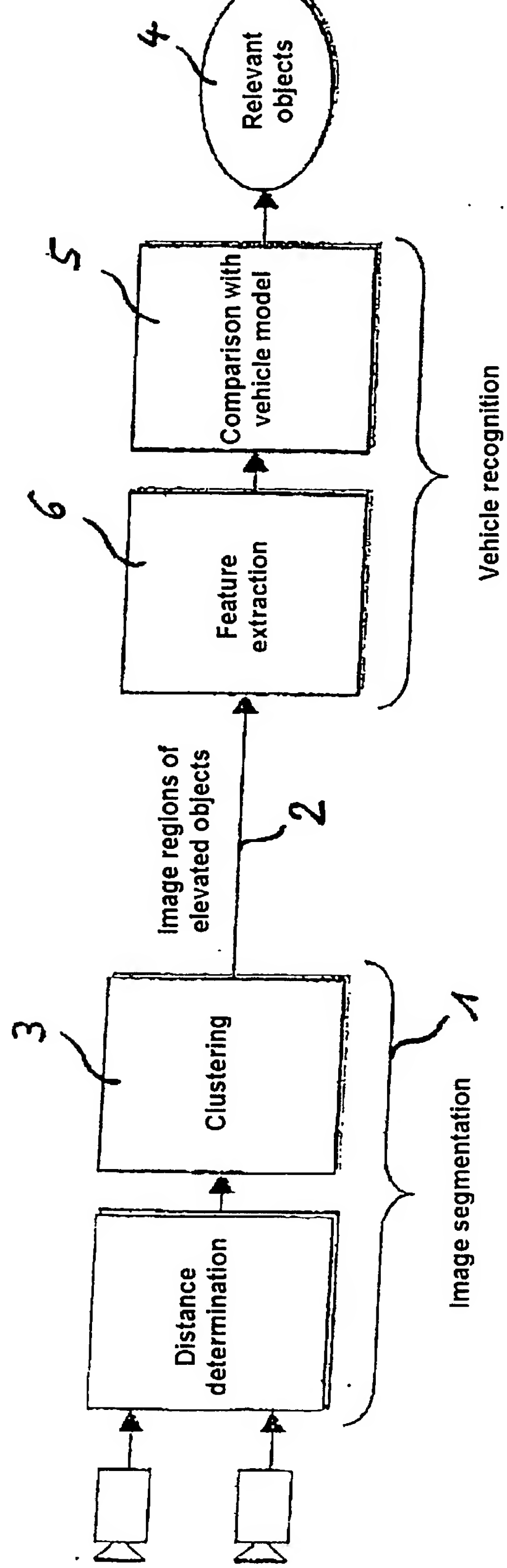

Relevant objects
4
Comparison with vehicle model
5
Feature extraction
6
Vehicle recognition
Image regions of elevated objects
2
Clustering
3
1
Distance determination
Image segmentation

Fig. 1

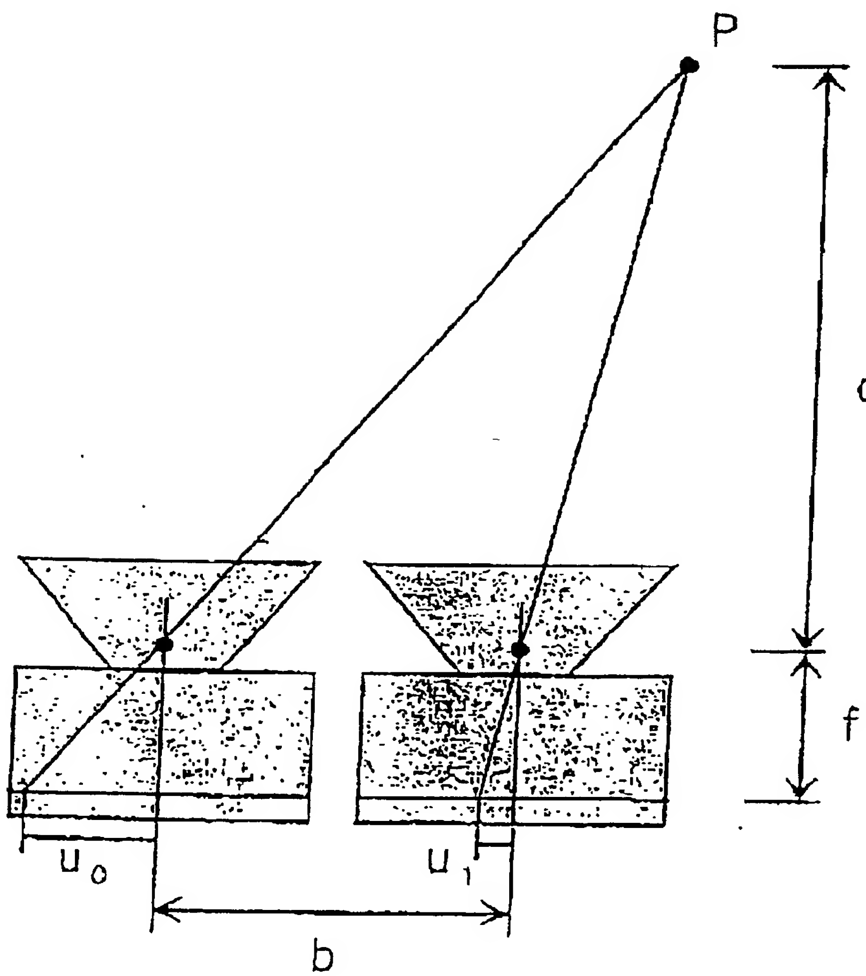


Fig. 2

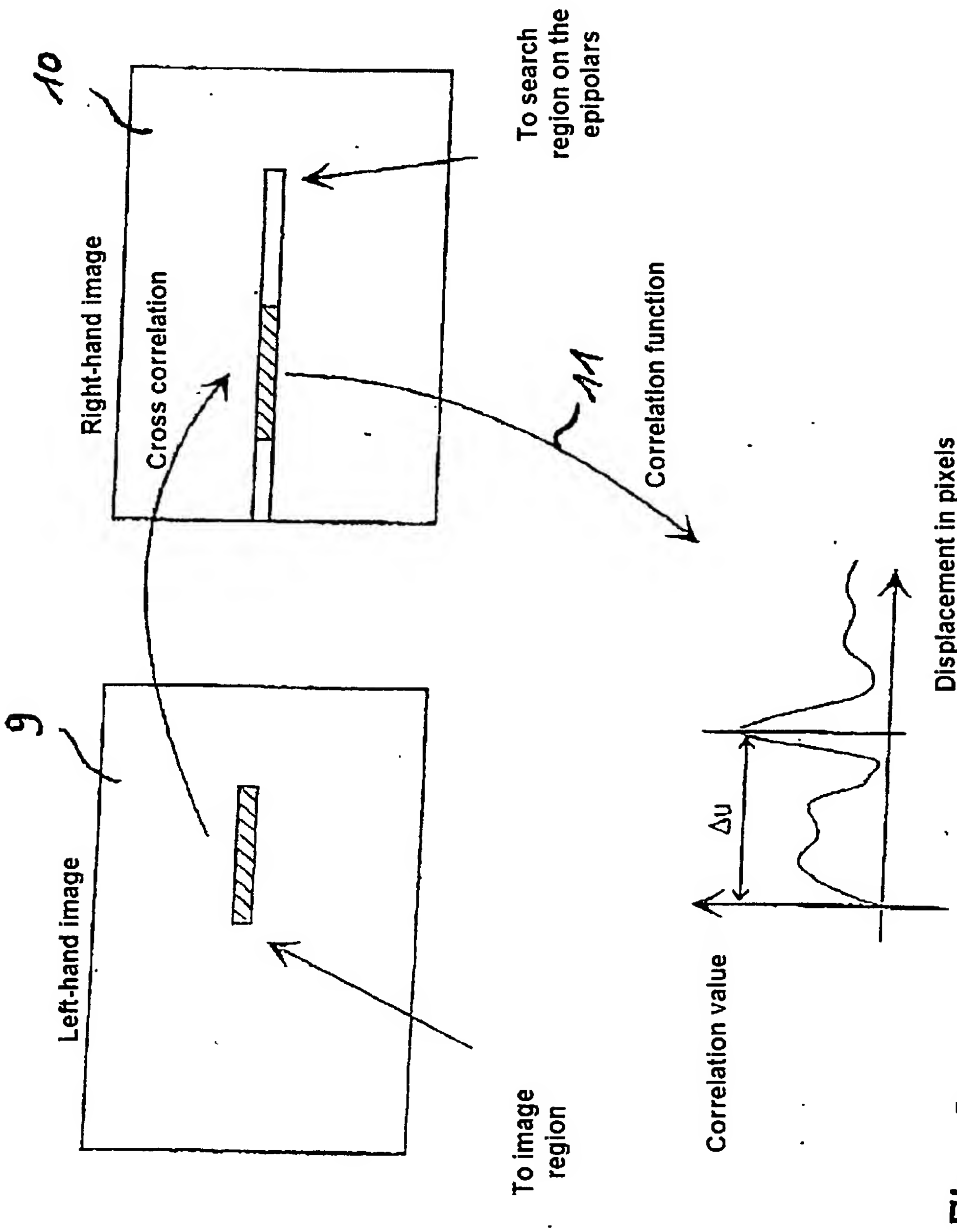

10
Right-hand image
Cross correlation
To search region on the epipolars
11
Correlation function
9
Left-hand image
To image region
Correlation value
Δu
Displacement in pixels

Fig. 3

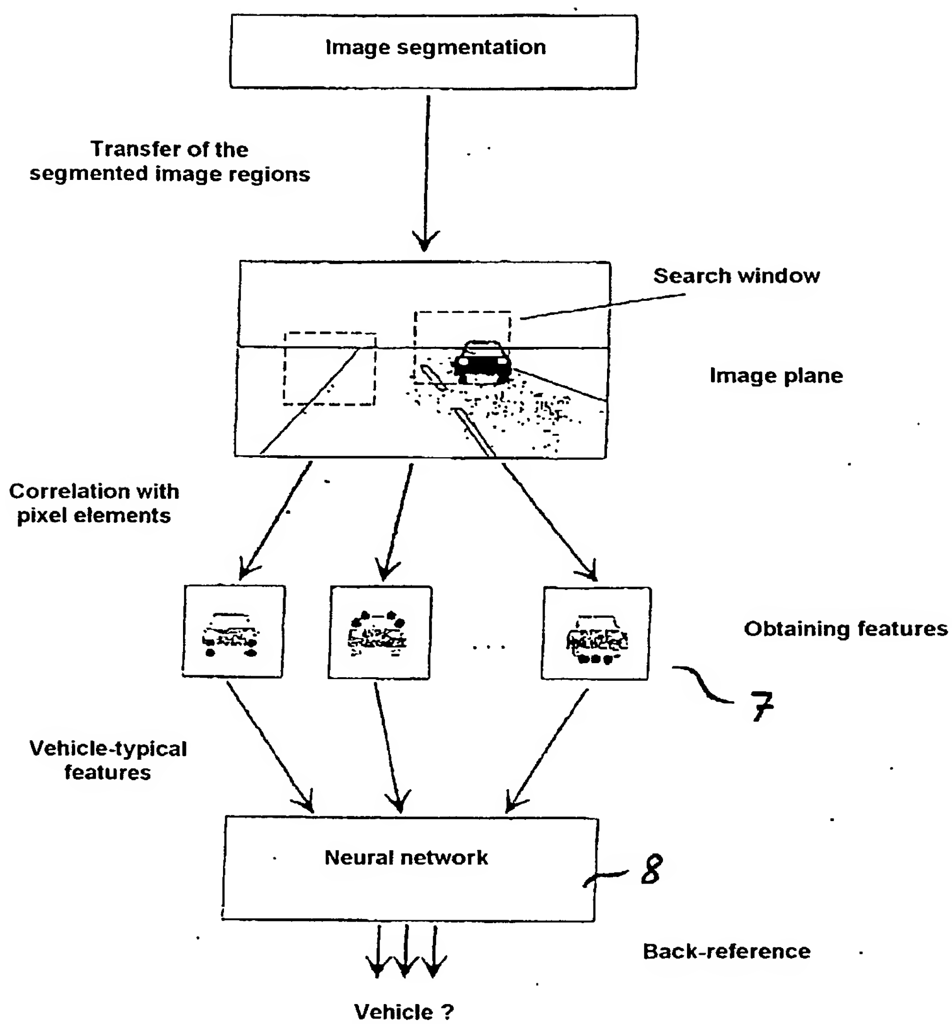


Image segmentation
Transfer of the segmented image regions
Search window
Image plane
Correlation with pixel elements
Obtaining features
7
Vehicle-typical features
Neural network
8
Back-reference
Vehicle ?

Fig. 4

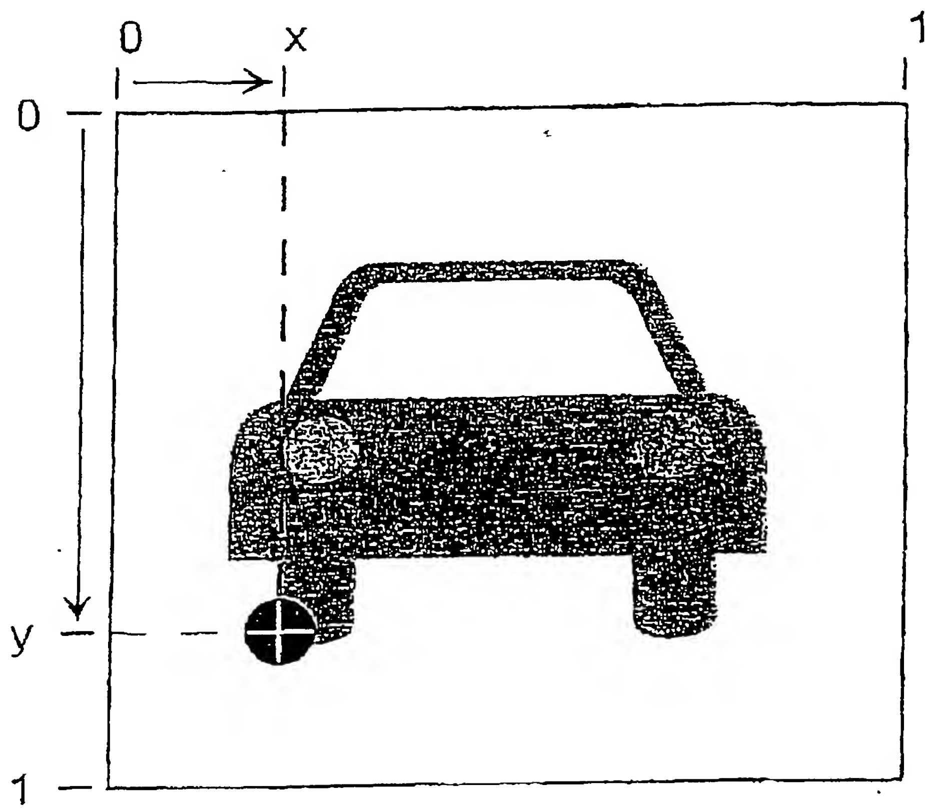


Fig 5

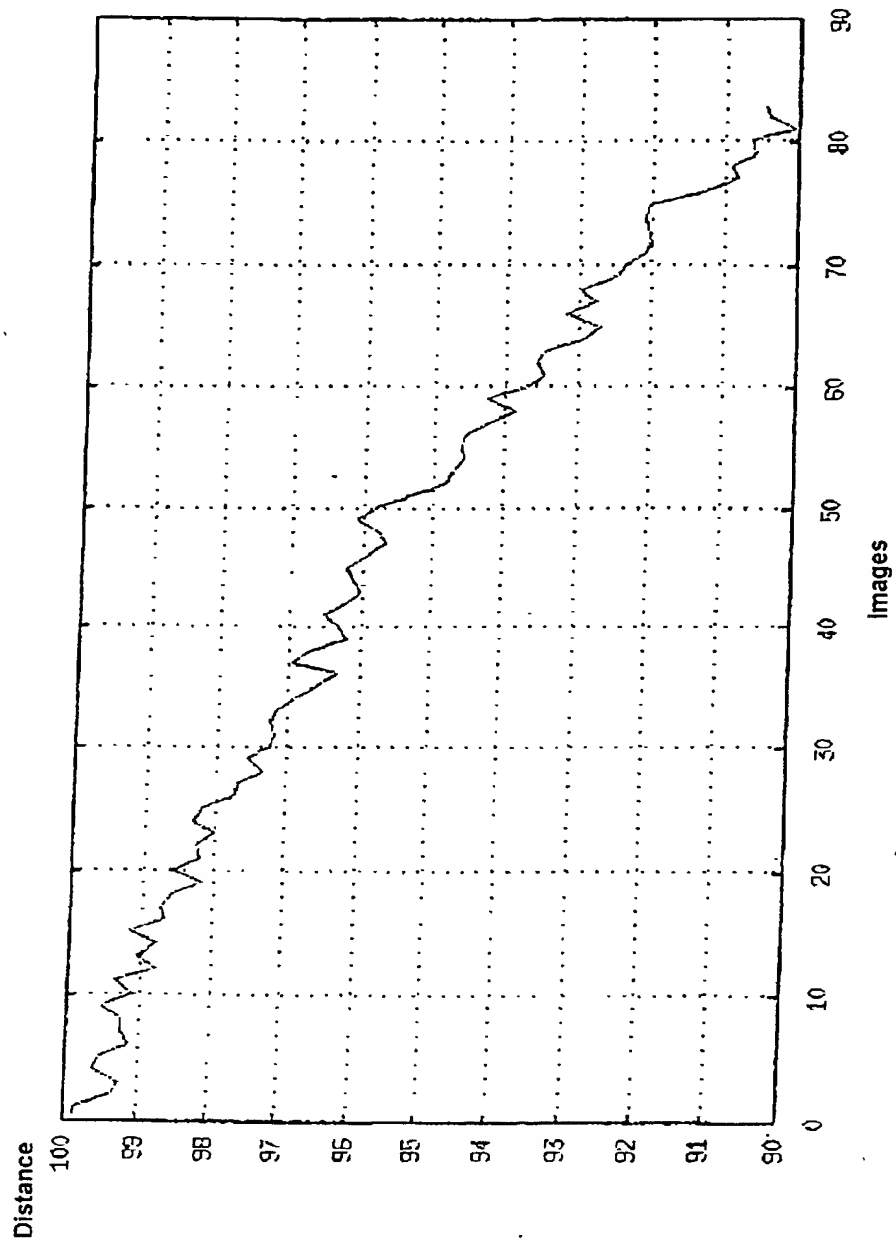

Distance
100
99
98
97
96
95
94
93
92
91
90
0
10
20
30
40
50
60
70
80
90
Images

Fig. 6

COMBINED DECLARATION FOR PATENT APPLICATION AND POWER OF ATTORNEY (includes Reference to PCT International Applications)	ATTORNEY'S DOCKET NUMBER 225/50731

As a below named inventor, I hereby declare that:

My residence, post office address and citizenship are as stated below next to my name.

I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled:

METHOD OF DETECTING OBJECTS IN THE VICINITY OF A ROAD VEHICLE UP TO A CONSIDERABLE DISTANCE

the specification of which (check only one item below):

[ ] is attached hereto.

[ ] was filed as United States application
Serial No.
on
And was amended
on _______________ (if applicable).

[X] was filed as PCT international application
Number PCT/EP00/05337
on 9 June 2000
and was amended under PCT Article 19
on _______________ (if applicable).

I hereby state that I have reviewed and understand the contents of the above-identified specification, including the claims, as amended by any amendment referred to above.

I acknowledge the duty to disclose information which is material to the examination of this application in accordance with Title 37, Code of Federal Regulations. §1.56(a).

I hereby claim foreign priority benefits under Title 35, United State Code, §119 of any foreign application(s) for patent or inventor's certificate or of any PCT international application(s) designating at least one country other than the United States of America listed below and have also identified below any foreign application(s) for patent or inventor's certificate or any PCT international application(s) designating at least one country other than the United States of America filed by me on the same subject matter having a filing date before that of the application(s) of which priority is claimed:

PRIOR FOREIGN/PCT APPLICATION(S) AND ANY PRIORITY CLAIMS UNDER 35 U.S.C. 119:

COUNTRY (if PCT indicate PCT)	APPLICATION NUMBER	DATE OF FILING (day, month, year)	PRIORITY CLAIMED UNDER 35 USC 119
Germany	199 26 559.3	11 June 1999	[X] Yes [ ] No
			[ ] Yes [ ] No
			[ ] Yes [ ] No
			[ ] Yes [ ] No
			[ ] Yes [ ] No

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Combined Declaration For Patent Application and Power of Attorney (Continued) (includes Reference to PCT international Applications	ATTORNEY'S DOCKET NUMBER **225/50731**

I hereby claim the benefit under Title 35, United States Code, §120 of any United States application(s) or PCT international application(s) designating the United States of America that is/are listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in that/those prior application(s) in the manner provided by the first paragraph of Title 35, United States Code, §112, I acknowledge the duty to disclose material information as defined in Title 37, Code of Federal Regulations, §1 56(a) which occurred between the filing date of the prior application(s) and the national of PCT international filing date of this application:

PRIOR U.S. APPLICATIONS OR PCT INTERNATIONAL APPLICATIONS DESIGNATING THE U.S. FOR BENEFIT UNDER 35 U S C 120

U S APPLICATIONS			STATUS *(Check one)*		
U.S. APPLICATION NUMBER	U S FILING DATE		PATENTED	PENDING	ABANDONED
PCT APPLICATIONS DESIGNATING THE U S					
PCT APPLICATION NO	PCT FILING DATE	U.S. SERIAL NUMBERS ASSIGNED (IF ANY)			

POWER OF ATTORNEY As a named inventor, I hereby appoint the following attorney(s) and/or agent(s) to prosecute this application and transact all business in the Patent and Trademark Office connected therewith (List name and registration number)

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203	RESIDENCE & CITIZENSHIP	CITY	STATE OR FOREIGN COUNTRY	COUNTRY OF CITIZENSHIP
	POST OFFICE ADDRESS	POST OFFICE ADDRESS	CITY	STATE & ZIP CODE/COUNTRY

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true: and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under section 1001 of Title 18 of the United States Code, and that such willful false statements may jeopardize the validity of the application or any patent issuing thereon

SIGNATURE OF INVENTOR 201	SIGNATURE OF INVENTOR 202	SIGNATURE OF INVENTOR 203
C. Knoeppel	Uwe Regensburger	
DATE 20.12.2001	Date 20.12.2001	DATE.